

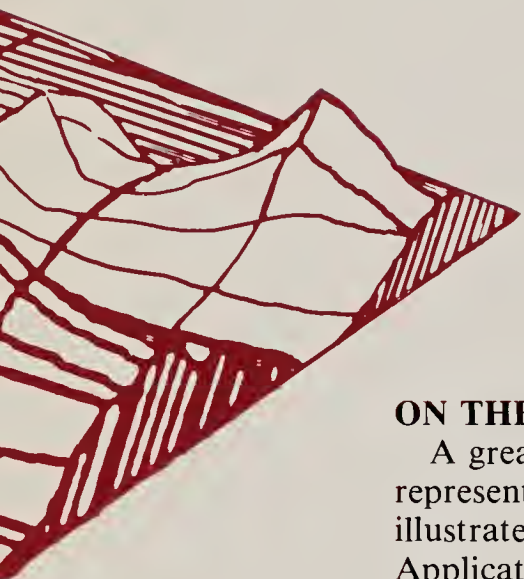


Department of  
Veterans Affairs

# Rehabilitation R&D Progress Reports

1989

Veterans Health Services and Research Administration  
Rehabilitation Research and Development Service



#### **ON THE COVER**

A greatly enlarged photograph of a microchip superimposed on a graphic representation of a three-dimensional spectral plot of speech and binary code to illustrate the concept of digital microprocessing technology applied to hearing. Applications of digital microprocessing technology are expected to revolutionize the abilities of hearing aids over the next decade. The Department of Veterans Affairs is playing a leading role in this pioneering research. One procedure based on digital signal processing is under development at the Central Institute for the Deaf and Washington University, St. Louis, MO. The project is sponsored by the VA Rehabilitation Research and Development Service. A report on the progress of this work, "Development of a Digital Hearing Aid and Computer-Based Fitting Procedure: Phase II," is on page 422.

*(Cover design by Holly Jellison; production by Frank Vanni, VA Prosthetics Assessment and Information Center. Microchip photograph by MOSIS Photos, Melgar Photographers, Inc., Santa Clara, CA; ear photograph by Nick Lancaster, VA Prosthetics Assessment and Information center)*



# **Rehabilitation R&D Progress Reports**

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## **1989**

AMERICAN FOUNDATION FOR THE BLIND  
15 WEST 16th STREET  
NEW YORK, NY 10011

**Rehabilitation R&D Progress Reports**  
is a publication of  
**The Department of Veterans Affairs**  
**Veterans Health Services and Research Administration**

Rehabilitation Research and Development Service  
Office of Technology Transfer (110A1)  
VA Prosthetics Research and Development Center  
103 South Gay Street  
Baltimore, MD 21202

# GUIDELINES FOR SUBMITTING PROGRESS REPORTS IN 1990

The VA Rehabilitation Database on CompuServe allows submission of reports to be more flexible, and the contents more current. We encourage contributors to send reports as soon as new progress is made so that their work can be updated on the database throughout the year. Additional and/or progress reports not yet in the database will be added as they are received. Reports will bear the date of receipt to identify new and/or updated material. (Date of receipt will not be included in the hard copy publication.)

## DEADLINE

Reports for publication in the 1990 *Progress Reports* must be received in this office by **September 17, 1990**.

## SUMMARY OF REQUIREMENTS

### GENERAL INFORMATION

Each report must include the following information:

1. Full names, titles, and addresses of the principal investigator and coauthors and location of the research activity.
2. Telephone number of the principal investigator.
3. Full name and address of the sponsoring organization(s), as well as the specific funded program. Include name of organization's director, if applicable.
4. Complete and accurate references (i.e., exact title, author(s), publication title, volume, issue number, date, and page numbers). Incomplete references will be deleted.
5. A list of key words (helpful for the *Progress Reports* Subject Index).
6. A suggested category listing (based on categories included in this book).

### TEXT

Text of reports may not exceed 600 words. The *Progress Reports* are published solely as statements of investigators on the current status of their work, and not as short research papers. Reports must be typed or printed, double-spaced format, with clearly marked page numbers. Enclose a copy of the same material on diskette (nonreturnable). We can use files saved in pure ASCII format under PC-DOS or MS-DOS, either 5 1/4-inch or 3 1/2-inch diskettes. You may send it through CompuServe. Our CompuServe Mail ID is 76703,4267.

1. ORGANIZATION: The text should contain a brief summary of the **Purpose, Progress, Methodology, Results (Preliminary or Final)** over the past year, and may contain a brief statement of **Future Plans/Implications**, if appropriate. **Recent Publications Resulting from This Research** may include citations from the last two years only (i.e., 1989 and 1990), as well as information on **Patents** and **Awards**. References must be published or accepted for publication only.
2. ILLUSTRATIONS: Do not include figures, tables, or photographs.
3. EDITORIAL CHANGES: Since galley proofs are not sent on *Progress Reports* submissions, any editorial changes made to meet publication requirements will be final, and not subject to author review.

## CORRESPONDENCE

Address contributions to:

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# Rehabilitation R&D Progress Reports 1989

Vol. 26 Annual Supplement of the *Journal of Rehabilitation Research and Development*

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## DISTRIBUTION/CIRCULATION POLICY

*Rehabilitation R&D Progress Reports* is distributed as an annual supplement of the *Journal of Rehabilitation Research and Development*. The mailing list is intended to cover all professionals in the rehabilitation field who are either actively involved in research, contemplate such involvement or need to remain familiar with the direction and methods of the current research and the clinical application of its results.

At present, the *Journal* and the progress report annual publication are distributed free of charge, both in the United States and in foreign countries. Additions will be made to the mailing list upon request.

The *Journal of Rehabilitation Research and Development* and its supplements are printed on acid-free paper, as of Vol. 25 No. 2 (Spring 1988).

## Editor's Note

The *Rehabilitation R&D Progress Reports 1989*, annual supplement to the *Journal of Rehabilitation Research and Development*, is the seventh compilation of ongoing work in rehabilitation research and engineering activity. We have continued our efforts to improve comprehensiveness and readability. Note that each progress report is numbered in brackets preceding the title of the report. These numbers are used to cross reference reports to other subject areas in the book of relevance to their topic. Reference numbers appear below each chapter heading. In addition, the subject index has been further expanded to facilitate the access of information for the reader.

Thanks to those who responded to the reader survey which was circulated with the 1988 issue. These comments have been helpful in further improving the quality and usefulness of the *Progress Reports*. Readers overwhelmingly praised the value of the publication. Ninety-seven percent of the respondents described ways in which the *Progress Reports* have been useful to them. Sample responses include the following.

In the area of information transfer:

- “Very beneficial to realize what current concepts in specific areas of rehab are working and what are not. Gives me a better understanding of my work.”
- “Helps to keep our department updated on the latest regarding rehabilitation R&D. Much of the equipment and service purchases we make are based on research results.”
- “Useful in connection with my duties as rehab director in a 400-bed hospital.”
- “Gives access to topics which I would not normally encounter in my journal reading.”
- “I am a paraplegic and they have kept me abreast of developments in orthotics.”
- “Very up-to-date and helpful in planning new research.”
- “Provides information on ongoing research, often before available in other sources.”
- “Have been able to send copies to other medical professionals as public relations or to back up our own theories.”
- “Identifies emerging trends in clinical practice.”
- “Helps to prevent duplication in research.”

As a resource:

- “One of the widest research indexes in this field.”
- “Piques interest and is a start for library research.”
- “Gives contacts, names, addresses; is a clearinghouse resource.”
- “Is a desk reference, good for networking too.”
- “Useful for me in teaching and lecturing.”

Some respondents recommended expanding the scope of coverage to include such topics as vocational rehabilitation, mental disabilities, and disability and rehabilitation management associated with chronic illnesses (in particular, AIDS). These recommendations are being considered. Several readers asked that more information on research completion schedules be included, and schedule information will be solicited from contributors to the 1990 issue. Some readers with specific areas of interest asked about the feasibility of splitting the *Progress Reports* into several topical publications. While this is an attractive idea, printing a single volume is most cost-effective at the present time.

Seventy-five percent felt that the length of reports was “just right,” 24 percent too short, and 1 percent too long. Twenty-six percent of the respondents felt that scientists could improve their reports by eliminating jargon and increasing objectivity in reporting. Almost all respondents (95 percent) reported that the subject categories, topical table of contents, and the subject index were easy to use and made the information highly accessible.

The *Progress Reports* clearly serve a wide range of users and uses, including research planning, support of clinical practice, and provision of information to individuals with disabilities. We welcome your continued comments and ideas for further improvements.

Seldon P. Todd, Jr.  
Editor, *Journal of Rehabilitation Research and Development*



# Rehabilitation R&D Progress Reports 1989

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### **ELECTRONIC PUBLISHING: A TECHNICAL NOTE**

We organized the progress reports in this publication with a multiuser database. We prepared the text documents in Microsoft Word (PC DOS version 4.0). We combined the use of the database and the word processor by performing sorts in the database and automatically loading files in the order defined by the sorts. Our database manager was the VA Fileman, running under Micronetics Multiuser Mumps (MSM) on a Dell PC AT. Mumps is an ANSI standard programming language. VA Fileman is a public domain database management system maintained by the Department of Veterans Affairs. We used the database to produce the table of contents, the author index, the subject index and the sponsor index. We also used the database to cross reference progress reports. John Bowman and Charles Moore, OTT Technical Support Group, designed the database structures. John Bowman developed the sort procedures and the interface with Microsoft Word.

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- 345 Quantification of Motor Coordination of the Lower Limb in Normal and Hemiparetic Subjects
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- 347 Development of an Outcome-Oriented Head Injury Database
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- 381 Dexter: A Mechanical Fingerspelling Hand for Deaf-Blind Users
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- 375 Identification of Differential Costs and Time Usage of Blind and Visually-Impaired Persons
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- 376 Sensory Aids for the Blind and Visually Impaired
- 376 SKERF-Pad Computer Access System
- 376 Smith-Kettlewell Volatile Braille Display
- 377 Flexi-Meter
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- 377 General-Purpose Stored-Speech Board (Nattering Ram)
- 378 Temperature-Controlled, Quick-Heating/Fast-Cooling Soldering Iron
- 378 Carpenter's Level
- 379 Stud Finder
- 379 Non-Damaging Low-Resistance Ohmmeter
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### A. Blindness and Low Vision

#### 2. Mobility Aids

- 395 Motorized and Autofocus Control Systems for Telescopic Low Vision Aids
- 396 Measuring the Spatial Layout Knowledge of Visually-Impaired Adults
- 397 Development of an Objective Measure of Orientation Skill: A Pilot Study
- 397 Orientation and Mobility for Blind Adults Over 60 Years of Age
- 398 Analysis of Navigation Without Sight
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- 399 Visual Perception and Orientation/Mobility in Low Vision

### A. Blindness and Low Vision

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- 402 Evaluation of Electronic Travel Aids (ETAs) for Visually Impaired Individuals
- 403 Graphics Environment Integrated Software Package for Blind Users
- 404 Effect of Control on Text Presentation



- 405 State-of-the-Art Planning Workshop on Access to Graphical Operating Systems for Blind Computer Users
- 405 Access to Graphics-Based Operating Systems for Blind Individuals: "Systems 3" Model
- 406 Textskimmer: A Handheld Reader for the Visually Impaired
- 407 Electronic Braille Page Output Device Using Nitinol
- 407 Psychophysics of Reading: Normal and Low Vision
- 408 Studies of Low Vision Reading and Face Recognition
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- 418 Prospective Randomized Cooperative Study of Advanced Cochlear Implants
- 418 Non-Auditory Factors Affecting Hearing Aid Use in Elderly Veterans
- 419 Coupler to Real Ear Transformations for Hearing Aid Selection: A Pilot Study
- 420 Measurement and Prediction of Benefit from Amplification
- 421 Studies on Amplification Selection for the Hearing-Impaired Veteran
- 422 Development of a Digital Hearing Aid and Computer-Based Fitting Procedure: Phase II
- 423 Basic Mechanisms and Rehabilitative Strategies for Presbycusis: Part I
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- 425 Auditory Alarms Project
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- 428 Acoustic Vowel Measures Following Radiation Therapy to the Larynx
- 429 Development and Evaluation of an Expert System to Facilitate Efficient Matching of Disabled People to Communication Devices

- 430 Assessment of the Effectiveness of a Small, High Quality Speech Synthesizer in Augmenting the Communication of Non-Speaking Individuals
- 431 Determinants of Intelligibility in Dysarthric Speech
- 431 Developing HAMLET: An Emotional Synthetic Speech System

### **C. Speech Impairment**

#### **2. Hearing-Related**

- 432 Auditory Prosthesis for Sensorineural Hearing Loss

### **C. Speech Impairment**

#### **3. Aphasia**

- 433 Hierarchical Computerized Language Treatment for Aphasic Adults
- 434 Cortical Auditory Evoked Potentials and Behavioral Measures of Aphasia
- 435 Development of Microcomputer and Clinician Treatment Procedures for Aphasia
- 435 Chest Wall Kinematics in Alaryngeal Speakers: A Pilot Study
- 436 Characteristics of Tracheoesophageal Voice in Four Prosthetic Occlusion Conditions
- 437 Influence of Mode of Stimulation on Naming Performance in Aphasia
- 438 Perceptual and Acoustical Characteristics of Tracheoesophageal Voice
- 439 An Experimental Analysis of Response Elaboration Training in Aphasia
- 440 Promoting Generalized Language Use: An Analysis of Treatment/Subject Variables
- 441 Computer Use by Aphasic Individuals
- 442 Signal Processing Device for Impaired Speech Assessment

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- 444 A Second Generation Mechanical Hand Communication Aid for the Deaf-Blind
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- 451 Cancer Patients' Home Care Needs and Costs
- 452 A Study of Treatment Choices Affecting Elderly Cancer Patients
- 453 Nurse Interventions Promoting Self-Help Response to Cancer

- 454 Neuropsychological Assessment of Children with Cancer
- 456 Self-Care Intervention to Decrease Chemotherapy Morbidity
- 457 Living with Homecare: Cancer Patients and Their Caregivers

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- 458 Evaluation of One-Way Air Flow Valve Prostheses in Decannulation Procedures for Chronic Tracheotomized Patients
- 459 Dissemination of Rehabilitation Technologies
- 459 Rehabilitation Effects of Expectation, Reward, and Activity on Subtypes of Schizophrenia
- 460 Major Study on Alcohol, Drugs, and Disability
- 461 State-Wide Interagency Planning Council on Technology Access for Persons with Disabilities
- 462 Establishing a State-Wide Technology Information Network

- 463 Consumer Role in State-Wide Planning for Access to Assistive Technology
- 463 Computerization of Patient Care Activities
- 464 Developing Consumer Criteria for Evaluating Assistive Devices
- 465 Primary Care for Persons with Physical Disabilities in the Netherlands
- 466 Comparison of the Costs of Supporting Children with Severe Disabilities in Family and Institutional Settings
- 467 Qualitative Evaluations of Exemplary Programs
- 467 Personal Integration Inventory
- 468 A Managed Primary Health Care Program for Working-Age Persons with Physical Disabilities: Planning for Implementation
- 469 Health Insurance-Related Work Disincentives for SSDI Beneficiaries
- 470 Rehabilitation Engineering Center
- 471 Drug Effects on Bladder Smooth Muscle Contractility



# I. Amputations and Limb Prostheses

## A. General

### [1] Mechanism-Based Treatments for Phantom Limb Pain

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A314-2RA)

**Purpose**—The purpose of this study is to determine causes and mechanisms of phantom pain and to test treatments based on identified mechanisms.

**Methodology**—Amputees reporting stump and/or phantom limb pain were recorded using thermographic measures of near-surface body heat and surface electromyographic measures of muscle tension. Each subject was recorded between two and four times while reporting varied pain intensities. Each subject used a body map to identify areas with phantom sensation, no sensation, and normal sensations. When decreased blood flow in the stump is related to increased burning phantom limb pain, peripheral vasodilators and temperature biofeedback are used to decrease the phantom pain. When increased muscle tension and spasms in the stump are related to episodes of cramping phantom pain, muscle relaxants and muscle tension biofeedback are used to control the pain.

**Results**—*Physiological Mechanisms.* Among amputees, a consistent inverse relationship between intensity of pain and stump temperature relative to the intact limb occurred for burning, throbbing, and tingling descriptions of phantom limb pain and stump pain, but not for other descriptions. Surface electromyographic (EMG) recordings made while amputees are experiencing multiple, brief, discrete episodes of cramping phantom pain show a clear predictive relationship between start of spasms in the residual limb and onset of phantom pain. There is no convincing evidence that major personality

disorders are important in the etiology of chronic phantom pain. Evaluation of logs indicates that phantom limb pain can be affected by the external environment.

*Treatments.* The treatments described above have only been completed for three-fourths of the subjects, and follow-ups are not complete, so the encouraging results of these initial treatments cannot yet be confirmed.

**Future Plans**—If our treatments continue to work after a one-year follow-up, this will be the first time effective treatments for phantom pain will be available for the vast majority of amputees. We are beginning to record physiological factors and phantom pain in subjects' normal environments to establish predictive relationships between variables.

#### Publications Resulting from This Research

**Phantom Pain: A Lesson in the Necessity for Carrying Out Careful Clinical Research in Chronic Pain Problems.** Sherman R, Ernst J, Barja R, Bruno G, *J Rehabil Res Dev* 25(2):vii-x, 1988.

**Treatment of Post-Amputation and Phantom Limb Pain.** Sherman R, Barja R, in *Current Therapy of Pain*, K. Foley, R. Payne (Eds.), Ontario: B.C. Decker, 1988.

**Phantom Limb and Stump Pain.** Sherman R, in *Neurologic Clinics of North America*, R. Portenoy (Ed.), 7(2):249-264, Philadelphia: W.B. Saunders Co., 1989.

**The Mystery of Phantom Pain: Growing Evidence for Physiological Mechanisms.** Sherman R, Arena J, Ernst J, *Biofeedback Self-Regul* (in press).

**The Relationship Between Situational Stress and Phantom Limb Pain: Cross-Lagged Correlational Data from Six-Month Pain Logs.** Arena J, Sherman R, Bruno G, Smith J, *Psychosom Res* (in press).



## [2] A Program for Evaluating the Dysvascular Patient

**Bok Y. Lee, MD; Lee E. Ostrander, PhD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A086-4RA)

**Purpose**—This study seeks to develop the required methodology and instrumentation for measuring tissue perfusion and evaluating the functional integrity of the soft tissues within diseased limbs. The ultimate goal is appropriate digital and limb salvage. Where amputation or removal of soft tissue is necessary, a selection of the most distal level where primary wound healing will occur is sought. A surgical flap model has been used in a laboratory study to compare small vessel perfusion with tissue viability. Instrumentation has been designed to improve measurements of perfusion including the fluorometric dye indicator method of perfusion measurement, the measurement of perfusion by hydrogen gas inhalation and polarography, and the external measurement of viscoelastic properties of the limb.

**Progress**—The work with fluorometry has demonstrated successful measurement of perfusion during constant infusion of fluorescein as an alternative to bolus fluorescein injection. We have also developed methods for measurement which compensate the fluorescence readings for differences in skin pigmentation.

The hydrogen polarography has the advantage of providing perfusion information deep within the tissues. An application based on earlier work has been reported. We have also made progress in addressing the need for rapid perfusion measurements. A study of the transient response of hydrogen during wash-in has shown that certain components of the multi-exponential response following hydrogen probe insertion are more sensitive than others to the level of tissue perfusion. With this information, we are able to reduce the time to measurement following probe insertion and thereby obtain more rapid measurements. However, the progress with fluorometry, as well as the logistics involved in administering hydrogen gas by inhala-

tion, has meant that less attention is being given to the hydrogen method at present.

Viscoelastic measurements are being applied to the evaluation of the compartment syndrome which can occur with swelling of soft tissue within a muscle compartment enclosed by fascia. Both the chronic and the acute compartment syndrome have been considered. The objective is to evaluate internal pressures by changes in external measurements.

**Implications**—Cutaneous perfusion pressure measurements form a link between the mechanical properties and the perfusion measurements, and was the subject of earlier studies. The advantage of the method is that it provides a noninvasive evaluation of the driving force of the blood which produces local tissue perfusion. Current efforts in this direction are aimed at characterizing the optical properties of tissue as a function of wavelength in order to optimize probe design.

### Publications Resulting from This Research

**Cutaneous Pressure Photoplethysmography in Managing Peripheral Vascular Disease.** Ostrander LE, Lee BY, Cui W, *Frontiers of Engineering and Computing in Medicine and Biology*, New York: IEEE Press, 1987.

**Effect of Lumbar Sympathectomy on Muscle Blood Flow.** Lee BY, Ostrander LE, Thoden WR, Madden JL, *J Rehabil Res Dev* 24(3):1-8, 1987.

**Intraoperative Assessment of Intestinal Viability.** Lee BY, Ostrander LE, Silverman DA, Thoden WR, Madden JL, McCann WJ, *NY Med J* 7:114-117, 1987.

**Use of Cutaneous Pressure Photoplethysmography in Managing Peripheral Vascular Disease.** Lee BY, Ostrander LE, Thoden WR, Madden JC, *Contemp Surg* 30:58-67, 1987.

**Constant Infusion Fluorometry to Predict Flap Survival.** Ostrander LE, Lee BY, Silverman DA, Groskopf RA, *Decubitus* 2:40-46, 1988.

**Noninvasive Method for the Assessment of Anterior Tibial Compartment Syndrome.** Ostrander LE, Lee BY, Cui W, *Surg Forum* 39:539-541, 1988.

**The Management of Peripheral Vascular Disease in the Spinal Cord Injured Patient.** Lee BY, Ostrander LE, in *Comprehensive Management of the Spinal Cord Injured Patient*, B.Y. Lee, et al. (Eds.), Philadelphia: W.B. Saunders Company (in press).



### [3] Intraoperative Assessment of Amputation and Decubitus Flap Perfusion

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Yale University Medical School, New Haven, CT 06510

**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A463-RA)*

**Purpose**—Early evaluation of perfusion in surgical flaps following their formation would permit early correction of conditions which lead to flap failures. These flaps are used in the treatment of nonhealing decubitus ulcers and, following amputation, covering the end of the limb. Failures can occur principally along both sides of the wound closure where the suturing is done, and where the tissue function in the vicinity of the suture may be compromised. Because testing is done following flap formation, and after the flap has been moved to its anticipated location, the results should be a better predictor of survival than testing done preoperatively.

**Progress**—We have proceeded with the design and implementation of equipment suitable for fluorometric measurement in the intraoperative environment. Additional noninvasive estimates of perfusion are provided by cutaneous pressure photoplethysmography and oximetry. Preliminary clinical studies have shown a relationship between flap failure and low fluorometric readings while using the method of dye administration by constant infusion.

#### **Publications Resulting from This Research**

None reported.

### [4] Cosmetic Covers for Upper and Lower Extremity Prostheses

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**Robert A. Erb, PhD**

Franklin Research Center, Norristown, PA 19403

**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A452-RA)*

**Purpose**—This program is the continuation of our work on technology that has been developed at Franklin Research Center (FRC) concerning realistic cosmetic covers for upper and lower extremity prostheses for men and women. Objectives include: 1) continuing the development and demonstration efforts begun under the previous VA contract with FRC, toward realistic and durable cosmetic covers for hand and arm prostheses, including procedures for molding, casting and intrinsic coloration, and application studies with silicones and other polymeric materials; 2) conducting technology transfer and training of VA-associated prosthetists in the specialized techniques of this program, including manuals and videotapes on procedures, and direct training sessions; 3) conducting research and development studies toward application of the cosmetic covers to active hand systems, including FRC's conforming-grasp design; and, 4) developing cosmetic covers for lower extremity prostheses (feet and legs).

**Progress**—Work on this follow-up project began in March 1989. The technology of making quickly-formed evertable donor molds was advanced through the development of tear-resistant outer layers, using hydride-type silicone curing reactants. Other efforts were carried out on factors in release-agent effectiveness with silicone casts in silicone molds, and on improved systems for intrinsic coloration.

The first two-day training session on the materials and techniques of the VA program at FRC was held in September 1989 for six VA prosthetic personnel and providers. The areas covered included primary molding and appliance fabrication with multilayer intrinsic coloration.

A conformable-grasp active hand model was fabricated with the design modified to provide for actuation by means of two small 12 V DC solenoids. Studies were also made of skin movement over finger joints, aimed toward designing active hand



cosmetic covers with realistic deformational characteristics.

**Results**—Experiments were conducted to study the problem of providing substantial stretching where needed, without excessive resistance to joint flexure. Molds at three angles of flexing were made of a human knee area which had been grid-marked with elevated points. Measurements taken from the three epoxy casts made from the silicone primary molds provided data on stretching behavior of the skin longitudinally and transversely during knee flexure (from full extension to a 70 degree included angle).

Interesting findings include: there were two maxima of longitudinal stretching—one above (about 70 percent elongation) and one below the patella; transverse contraction occurred in a number

of areas; and significant longitudinal elongation of the skin was occurring a large distance (e.g., 20 cm) from the center of the knee during its flexion. This information, along with that from planned ankle-flexion studies, will be used to help design low-modulus cover structures.

**Future Plans**—A major emphasis on this new program is in cosmetic covers for lower extremity prostheses. Problems that remain include: how to integrate cosmetic covers with the various designs of lower extremity prostheses, how to achieve the necessary durability along with realistic appearance, and how to provide substantial stretching where needed, without excessive resistance to joint flexure.

#### **Publications Resulting from This Research**

None reported.

## **[5] Computerized Methods for Prosthetics and Orthotics**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—This work looks at structure as related to prosthetics and orthotics: structure of the body, structure of devices, and the mechanical interaction between the structures. That is: 1) quantization of body structure is via digital image processing of computer tomography (CT) scans and via development of a mechanical digitizer for shape and stiffness measurement; 2) finite element analysis is used for structural modeling of the above-knee amputee prosthesis; 3) a numerical definition of rectification patterns for the socket of a below-elbow prosthesis will enable automated socket design; and, 4) stereolithography is used for the direct fabrication of the sockets from a computer-aided design (CAD) database.

**Progress**—*Structural Characterization.* A tactile, mechanical digitizer is under development which will allow measurement of both exterior surface shape and surface stiffness of body segments. Several features have been prototyped as isolated units, and we are now planning for the prototype of an integrated unit.

Using digital image processing techniques, we have written a program to distinguish the tissue boundaries in a CT image. The image is first filtered to remove noise. A histogram of the image intensities establishes appropriate threshold values for the materials of primary concern; bone, soft tissue, socket material, and air. Intensities are reassigned based on the threshold values. Finally, an edge-detection scheme is used to detect the borders between structures.

*Structural Processing.* A computer-based system for the automated design of below-elbow (B/E) sockets is underway. Parts of our below-knee (B/K) CAD/CAM system are being adapted for this purpose. Modification of the mechanical digitizer boom and fabrication of appropriate holding jigs now allows us to directly digitize positive models of the B/E limb.

The guidelines developed by John Billock for the Northwestern University Supracondylar Socket will be incorporated into an automated socket rectification program which can be applied to the digitized geometry.



Recent technological advances now allow direct fabrication of objects from CAD data files (Stereolithography, 3D Systems, Inc., and Laminated Object Manufacturing, Hydronetics, Inc.). Stereolithography forms solid models by optically curing a photopolymer with a computer-controlled laser. Through collaboration with Baxter Healthcare Corporation, we are able to use the stereolithography system for the production of socket models which have been designed using any of our structural processing schemes.

**Structural Modeling.** Work on modeling protocols using generic representations of residual extremities is focusing on factors such as appropriate element mesh configuration, since they form the underlying basis for the representation of physical systems as models. A constant dilatational strain restriction on a lower-order linear element seems to provide a good compromise between the representation of tissue incompressibility and solution time. A transferable mesh was developed which has a low optimized bandwidth, and provides for higher element density at the surface. Such a generic framework serves as a foundation for future models. Alterations are made to the nodal coordinates using internal and external geometrical data measured from any limb. This greatly simplifies

the time-consuming step of individual model generation.

**Preliminary Results**—We have also investigated the static mechanics of bulk muscular tissue in order to develop efficient techniques for modeling that response. The method developed has successfully accounted for the incompressible and large strain behavior occurring in easily deformable materials. This modeling method has been shown to be quite capable of predicting the measured force and surface profile in a soft elastomer which results from a large deformation. The method also accurately predicts the resultant force from deformation of *in vivo* muscular soft tissue. The methods developed from this work will be used in the modeling of above-knee residual limbs.

#### Publications Resulting from This Research

**Qualitative Aspects of the Mechanical Response of Living Muscular Tissue Under Compressive Loads.** Vannah WM, Childress DS, Steege JW, in *Proceedings of the 12th Annual Meeting of the American Society of Biomechanics*, Champaign, IL, 214-215, 1988.

**An Investigation of the Three-Dimensional Mechanical Response of Bulk Muscular Tissue: Experimental Methods and Results.** Vannah WM, Childress DS, *Computational Methods in Bioengineering Symposium of the 1988 ASME Winter Annual Meeting*, Chicago, IL, BED-9:493-503, 1988.

## [6] Information and Education Resource Unit

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Our primary goal is to develop a database in orthotics and prosthetics which will serve as a central clearinghouse/resource center on support organizations, clinical programs, educational centers, related materials, and sports and recreation programs for the disabled, as well as a host of technical information. Secondary support is being developed through linkages with clinicians, researchers, manufacturers, and existing databases which can complement our existing information and resources in the field of orthotics and prosthetics.

To date, we have found that information collection and dissemination through Northwestern

University's Rehabilitation Engineering Program on Orthotics and Prosthetics is serving a wide variety of users in multiple ways. Consumers are receiving information via direct requests to the Center, as well as indirectly through support and resources provided to numerous consumer groups across the country by the Information Unit. Consumers have also served as a source of information by participating in our national database which, to date, contains 132 entries of groups across the United States. Consumers have provided feedback to the Rehabilitation Engineering Program following the National Amputee Support Networking and Educational Meeting in



Orlando in February, 1989, and the Consumer Advisory Board Meeting in Chicago, in October, 1988. This feedback can be used by the Center staff as well as others in the field to verify consumer problems and address unmet needs in information and technology. Furthermore, consumer groups have been successfully linked to four major University programs to serve as participants in surveys on upper extremity prosthetic use, lower extremity prosthetic function, and satisfaction with prosthetic care and pain. These communication links between consumers and service providers will, we hope, enhance productivity and produce quality outcomes for the disabled.

Professionals involved with care of the disabled utilize our services in different ways. Through formal programs, we have provided them with information related to regional and national programs and resources in orthotics and prosthetics. In response to requests, we provide many practitioners with information, written materials, and other resources for use in patient education and program development. Currently, we are also working collaboratively to link providers of care with consumers, other professionals, and referral centers throughout the country.

**Progress**—In our first year of operation, a variety of materials have been evaluated and compiled into hard copy references for professionals and consumers on such topics as support groups, publications for the disabled, sports and recreational references, juvenile resources, etc. Computerized information on Amputee Resources is continually being evalu-

ated and updated. This base of information will expand to include orthotics as time and resources allow.

Collaboration with the Association of Children's Prosthetic-Orthotic Clinics, as well as the American Academy of Orthotics and Prosthetics, enabled us to develop educational offerings for practitioners as part of two national meetings this year. In addition, several exhibits have been developed. One, currently at Northwestern University's Rehabilitation Engineering Program, was displayed at the American Academy of Orthotics and Prosthetics Scientific Symposium and at the Annual Association of Children's Prosthetic-Orthotic Clinics Meeting to demonstrate existing consumer resources and networking in orthotics and prosthetics. A second exhibit, currently housed at the Area Amputee Center, was developed for teams in Children's Orthotic and Prosthetic Clinics to demonstrate an interdisciplinary model of care. Our staff also provided consultation to the University of Minnesota in developing the prosthetics portion of a new exhibit, entitled Bionics and Transplants, which is scheduled to travel to seven U.S. cities over the next three years.

At the present time, formal communications are beginning with larger databases to identify specific information which currently exists and to plan for filling gaps in orthotic and prosthetic information as we are able to do so.

#### **Publications Resulting from This Research**

None reported.

## **[7] Prosthetic/Orthotic Materials**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Standardized testing modalities are being used to characterize the composition, structure, and performance of the current armamentarium of prosthetic and orthotic polymers prior to and after

fabrication, and after weathering and aging. Also, new polymeric materials are being examined for their potential for providing improved prosthetic and orthotic devices.



**Progress**—The project is currently in the process of characterizing the Group I (solid) orthotic and prosthetic materials.

**Results—Tensile Testing.** Tensile testing was carried out on an Instron Model 1114 Testing Machine using ASTM D638. Five plastics were investigated in four heat-treatment conditions (as received, ice-quenched, air-cooled, and annealed), plus five weathering conditions (0, 2, 4, 6, and 8 weeks), testing five specimens per condition. This combination of parameters required a minimum of 500 samples. Weathering was performed according to ASTM G53-84, where at 60 degrees Centigrade a cycle of 8 hours of exposure to intense ultraviolet light, followed by 4 hours of water condensation, is repeated for up to 8 weeks.

The results for yield stress and ultimate tensile strength were as follows: Uvex > Durr-Plex > Polypropylene > Subortholen > Surlyn. These trends also held for all heat treatments and weathering conditions. As the strength decreased, the elongation to failure increased.

Heat treatments seemed to affect only the Polypropylene and the Subortholen materials. Ice-quenching these materials after heating tended to result in a loss of strength, and an increase in the percent elongation. However, these differences decayed with time. Weathering for up to 8 weeks did degrade the mechanical properties significantly. Surlyn was the only material to show any obvious change. Scanning electron microscopy confirmed that the surface and subsurface were fractured by weathering.

**Impact Testing.** Standard Charpy-type impact tests were performed using ASTM D256. Durr-Plex and Uvex both exhibited fairly low impact strengths (Uvex = 2.5 Kg-cm/cm and Durr-Plex = 2.1 Kg-cm/cm), implying that these materials tend to be brittle. The impact resistance of both Surlyn and Subortholen was greater than the testing machine's capacity (10 Kg-cm/cm), and thus neither failed

upon testing. A negative correlation exists between the strength of these materials and their impact toughness. Materials which exhibit the largest strengths during tensile testing have the lowest impact resistance and vice versa.

**Hardness.** The hardness was determined using two separate methods, namely: Barcol #935 spring-loaded pointed indenter and Rockwell L Scale. Both methods produced similar, but not identical, ranking with: Durr-Plex, Uvex, and Polypropylene > Subortholen and Surlyn. Quenching, heat treatment, and weathering left the hardness of Durr-Plex, Uvex, and Polypropylene essentially unchanged, but caused significant softening in Subortholen and Surlyn.

**Wear Tests.** Wear tests of five prosthetic and orthotic materials were carried out on a Taber Model 503 Abraser, using two rubber-based wheels each under 1 Kg load, cutting a 2.5-inch circle while rotating the test material at 1 cycle per second.

The weight loss was measured up to 30,000 cycles. Subortholen had the best resistance to this type of abrasive wear, Uvex and Polypropylene were next, followed by Surlyn, and then Durr-Plex showing the poorest resistance to wear. There were no obvious relationships between hardness and wear. Subortholen, the best abrasion resister, was one of the softer materials, while Durr-Plex, the poorest-wearing material, was much harder. There was also no positive or negative correlation between the tensile properties and abrasive wear.

**Future Plans**—Characterization activities are also being conducted in areas such as dynamic mechanical analysis, differential scanning calorimetry, X-ray diffraction, nuclear magnetic resonance, Fourier transform infra-red spectroscopy, and acoustic determination of modulus. Work is to begin on thermo-plastic elastomers (TPE's).

#### **Publications Resulting from This Research**

None reported.

## [8] Studies in the Use of Extended Physiological Proprioception as a Positioning Modality in Devices for Physically Disabled Persons

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**Sponsor:** *The Natural Sciences and Engineering Research Council; Henry White Kinnear Elizabeth Foundation*

**Purpose**—Major changes to the process, implementation, and applications of extended physiological proprioception (EPP) will be investigated in this study. They are as follows: 1) the fixed 1:1 relationship between input (joint position) and output (position of the terminal device of the prosthesis) will be selected by the user. This will enable the user to choose the optimum linkage prior to performing specific functions or group of functions. It will increase the usefulness of the prosthesis at the cost of an as yet unknown reduction in speed and accuracy. A major study is needed so that we can better understand the use of such selectable input/output relationships (linkages); and, 2) EPP could also be used in the control of devices other than prostheses to assist disabled clients. Body movements have been used for several years by physically disabled persons to control their manipulators. Researchers in the field of robotic aids are very conscious of safety considerations in their designs. For example, if a robot is used to feed a person, the terminal device must reach the mouth with sufficient power to carry the food. Even keeping the weight of the system (and therefore its inertia) to a minimum, there would be a constant risk of injury to the mouth, face, and eyes of the user. The risk can be reduced by giving the user some "proprioception" of the position in space of the terminal device. This would make the control more positive, and would add to the safety of virtually every robotic system.

**Methodology**—Computer simulations will be used for this investigation. This strategy has a number of

advantages over using prototype prostheses or bench models. The advantages include better control of extraneous cues obtained by subjects (e.g., when touching a target), complete elimination of unwanted visual cues, precise error measurement, and better score keeping.

The following questions will be addressed in the research: 1) Can the method of EPP be successfully modified by replacing the fixed 1:1 relationship between input and output, with pre-programmed selectable linkages? What loss in accuracy and speed will result? What increase in function will be obtained? and, 2) Will the principles of EPP be useful in the control of robotic systems for physically disabled persons? Investigating the above questions will involve: further refinements to our existing computer simulation system; the setting up of specific tasks to be learned and performed by volunteer subjects; the setting up of a scoring system to evaluate subject performance; and, the performance of experiments based on different types of prostheses and different robotic systems.

### Publications Resulting from This Research

- An Above Elbow Prosthesis Employing Programmed Linkages.** Gibbons DT, O'Riain MD, Philippe-Auguste S, *IEEE Trans Biomed Eng* 34(7):493-498, 1987.
- Position Proprioception in a Microcomputer-Controlled Prosthesis.** O'Riain MD, Gibbons DT, *Med Biol Eng Comput* 25:294-298, 1987.
- A Robot Feeder.** Sibille J, Goudreau L, O'Riain MD, in *Proceedings of the 13th Canadian Medical and Biological Engineering Conference*, Halifax, NS, 137-138, 1987.
- Simulation and Modeling of a Microcomputer-Controlled Above-Elbow Prosthesis.** Philippe-Auguste S, Gibbons DT, O'Riain MD, *Automedica* 1989 (in press).



## [9] Skin Microcirculation and Permeability as Revealed by Simultaneous Inert Gas Effluxes

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Sponsor: VA Rehabilitation Research and Development Service (Project #A335-RA, Part 1)

**Purpose**—The purpose of this study was to: 1) apply our three-dimensional skin blood flow model to experimentally-measured fluxes of helium, argon, and xenon in human subjects; 2) estimate blood flow at different depths in the skin; and, 3) estimate the stratum corneum resistances.

**Methodology**—We measured simultaneous gas fluxes *in vivo* from the skin of five healthy subjects, average age 25, breathing mixtures of 2 percent xenon, and approximately equal concentrations of helium, argon, and oxygen. Fluxes were measured from the volar aspect of the forearm with a mass spectrometer system, utilizing a temperature-controlled skin probe. Fluxes were measured at skin temperatures of 33, 36, 39, and 43 degrees centigrade, on two separate days, first in intact skin and then following removal of the stratum corneum using a formic acid technique.

**Results/Implications**—The average fluxes ( $\mu\text{l per min}\cdot\text{cm}_2\cdot\text{atm}$ ) of helium, argon, and xenon in *intact* skin with skin temperature at 33 degrees C were helium = 0.09, argon = 0.07, and xenon = 0.11. At 36 degrees C, helium = 0.11, argon = 0.09, and xenon = 0.13. At 39 degrees C, helium = 0.15, argon = 0.13, and xenon = 0.20. At 43 degrees C, helium = 0.48, argon = 0.40, and xenon = 0.52.

The average fluxes ( $\mu\text{l per min}\cdot\text{cm}_2\cdot\text{atm}$ ) of helium, argon, and xenon in *stripped* skin with skin

temperature at 33 degrees C were helium = 0.07, argon = 0.09, and xenon = 0.23. At 36 degrees C, helium = 0.12, argon = 0.22, and xenon = 0.31. At 39 degrees C, helium = 0.23, argon = 0.50, and xenon = 0.75, and at 43 degrees C, helium = 0.40, argon = 0.64, and xenon = 0.98.

Gas flux through human skin shows a complicated interdependence on microcirculation of the skin, diffusivity and permeability in the viable tissues, and stratum corneum resistance. The interdependence is amplified with fluxes measured through “stripped” skin as the flux is minimally affected by stratum corneum resistance. The use of multiple gases of differing blood solubility and tissue diffusivity provides information on blood flow distribution within the dermis. Conclusions reached from single measurements of gas fluxes or from a single subject should be avoided because there is a large degree of variability among subjects.

**Implications**—Improved diagnosis of vascular conditions and/or the determination of blood gas concentrations from gas flux measurements could be obtained in the future, from a more precise analysis of skin blood flow and diffusional resistance.

### Publications Resulting from This Research

Permeation of Inert Gases through Human Skin: Modeling the Effect of Skin Blood Flow. Whang JM, Baumgardner JE, Quinn JA, Graves DJ, Neufeld GR, *J Appl Physiol* (in press).

## [10] Amputation Site Viability Assessed with the Laser Doppler Velocimeter in Patients Scheduled for Surgery

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Sponsor: VA Rehabilitation Research and Development Service (Project #A335-RA, Part 2)

**Purpose**—The purpose of this study was to develop a preoperative test of skin viability at amputation sites using a laser Doppler velocimeter (LDV).

**Methodology**—We used a heated skin probe to control skin temperatures at 34, 38, and 42 degrees centigrade at the site of application of the LDV probe (PeriFlux model PF3). The LDV blood flow signal increases as a function of local skin temperature. The LDV versus temperature data were empirically fit to an exponential equation and the exponential coefficient determined from the data by regression analysis. We compared the exponential coefficients between patients whose amputations healed versus those that failed.

**Results**—We studied 55 patients, 37 of whom were diabetic, with a median age of  $64 \pm 8$ . These patients subsequently underwent a total of 89 amputations.

The laser Doppler velocimetry temperature response (LDVTR) at various amputation sites was as follows: dorsum of toes which heal—number of subjects (N): N=25 (mean 0.129, standard deviation

[SD] 0.053); mid-foot amputation which would heal—N=13 (mean 0.130, SD 0.062); mid-foot amputation which would not heal—N=10 (mean 0.040, SD 0.025); below-knee amputation (BKA)/calf which would heal—N=12 (mean 0.174, SD 0.073); BKA which would not heal—N=8 (mean 0.095, SD 0.025); above-knee amputation/thigh which would heal—N=9 (mean 0.212, SD 0.072).

The LDV temperature response is clearly different at amputation sites which heal, compared to those which do not heal. The test appears predictive in patients irrespective of skin color, and in this respect, is more reliable than the intravenous fluorescein test in predicting inadequate cutaneous perfusion.

**Implications**—The Laser Doppler Temperature Response Test appears to be a valuable, non-invasive tool in predicting the viability of an amputation site.

### Publications Resulting from This Research

See Part 1.

## [11] Skin Blood Flow Before and After Vascular Bypass Surgery Evaluated with the Laser Doppler Velocimeter

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Sponsor: VA Rehabilitation Research and Development Service (Project #A335-RA, Part 3)

**Purpose**—The purpose of this study was to determine if an increase or decrease in skin perfusion following vascular bypass surgery could be detected with a laser Doppler velocimeter (LDV).

**Methodology**—Twelve patients scheduled for a unilateral, distal extremity vascular bypass procedure were studied before and after surgery. We used a heated skin probe to control skin temperatures at

34, 38, and 42 degrees centigrade. The LDV (PeriFlux model PF3) blood flow signal increases as a function of local skin temperature. The LDV versus temperature data (laser Doppler temperature response or LDVTR) were empirically fit to an exponential equation and the exponential coefficient determined by regression analysis. Measurements were obtained from three sites. The control site was located on the upper arm and the two test sites were



on the dorsum of each foot. We compared the exponential coefficients of the test sites to the control site as percentage ratios before and after surgery. Ankle-Brachial Pressure Indices (ABI) were obtained within a day of the laser Doppler results. Patency of the graft was confirmed by obtaining a waveform from a pulse volume recorder.

**Results**—With the number (N) of patients = 12, the LDVTR at the control site (upper arm) prior to vascular surgery had a mean of 0.243 with a standard deviation (SD) of 0.100, while postsurgery, the mean was 0.244 with a SD of 0.062. Presurgery, the operative dorsum of the foot (ODF) (N=12), had a mean of 0.098 with a SD of 0.067; postsurgery the mean was 0.228 with a SD of 0.106. At the contralateral dorsum of the foot (CDF), with N=11 (one patient had a previous below-knee amputation), the presurgery mean was 0.190 with a SD of 0.106; postsurgery the mean was 0.164 with a SD of 0.052.

By multiplying the LDVTR results at the test sites and at the control site by 100 percent, the figures show the ODF (N=12) with a mean of 42 and a SD of 25; the postsurgery mean was 93 with a SD of 35. Using the same formula, the CDF (N=11) had a preoperative mean of 74 with a SD of 24 and a postoperative mean of 69 with a SD of 23.

The ankle/brachial indices at the ODF (N=12) had a presurgery mean of 0.38 with a SD of 0.24 and a postsurgery mean of 0.83 with a SD of 0.18. At the CDF (N=11), the presurgery mean was 0.74 with a SD of 0.29 and the postsurgery mean was 0.73 with a SD of 0.30.

**Implications**—The data show that an increase in the LDVTR coincided with an improvement in the ABI's.

#### **Publications Resulting from This Research**

See Part 1.

## **B. Upper Limb**

### **1. General**

#### **[12] Pilot Investigation of the Use of Cross-Correlation Analysis for the Discrimination of Function in Myoelectric Prostheses**

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**Sponsor:** *Variety Club of Ontario, Tent 28, Toronto*

**Purpose**—The overall objective of this project is to enhance the functional benefit of myoelectric prostheses by increasing the number of functions that the user can simultaneously control. To this end, the project team conducted a pilot study. The goals were to investigate whether cross-correlation analysis can be used to discriminate between patterns of upper-limb muscle activity; and, to ascertain the feasibility of training amputees to contract their muscles in the desired patterns.

**Methodology/Results**—Pairs of bipolar electrodes were placed on two subjects with intact limbs and

EMG recordings were taken as follows: 1) electrodes were placed at the proximal end of the posterior forearm, and at the distal end of the proximal third of the posterior forearm, placed close to the extensor digitorum and carpi ulnaris. The subjects were asked to extend their wrists, and to extend their middle fingers with their wrist relaxed; 2) electrodes were placed on the lateral side of the distal third of the humerus corresponding to the brachialis muscle, and on the central part of the biceps brachii. The subject flexed the elbow with the forearm in the prone position, and supinated the forearm while the elbow was flexed at 90 degrees; 3) electrodes were

placed on the medial side of the humerus and on the posterior side corresponding to the medial and long heads of the triceps brachii. The subject actively extended the elbow without resistance, and with the wrist and hand opposing a table. Cross-correlation analysis was performed.

The results indicated a distinct symmetrical peak (0.4 to 0.8) in the cross-correlation function for the first of all the above pairs of measurements. This was expected since each of these activities mostly involved one muscle. The peak was clearly absent in the second of the above pairs of measurements, where more than one muscle was responsible for the EMG activity (co-contraction).

A below-elbow traumatic unilateral amputee, amputated at mid-forearm, was also tested. Electrodes were placed as in (1) above. The subject's integrated EMG was fed back to him via two audio speakers and two analogue meters. The subject was asked to extend his wrist and middle finger on his non-amputated side first, so that he could become aware of the muscles involved in these two actions. He was asked to contract his muscles on the amputated side as if he were extending his middle finger without extending the wrist. He was then asked to contract his muscles as in full wrist extension. The subject was encouraged to palpate

his muscles with his contralateral hand and feel the difference between the two actions. After approximately five minutes of practice, the subject was able to differentiate the two actions successfully and repeatedly, even with the feedback removed.

**Future Plans**—Funding is currently being sought for a larger scale project with four goals: 1) to investigate the feasibility of using biofeedback techniques to train amputees for independent control of selected muscles within the elbow and wrist flexor and extensor groups; 2) to validate the use of cross-correlation analysis for discriminating among the patterns of muscle activity for which the amputees will be trained; 3) to develop a decision criterion (based on differences in the cross-correlation function), which discriminates between the different patterns of muscle activity and can be used in the real-time control of prostheses; and, 4) to evaluate the functional performance of individuals using a laboratory-based prosthetic prototype based on the analytical techniques developed in this research project.

#### **Publications Resulting from This Research**

None reported.

## **B. Upper Limb**

### **2. Above-Elbow**

#### **[13] Improvement of Body-Powered Upper-Extremity Prosthetic Components: A Modular Electromechanical Lock Actuator/A Positive-Locking Shoulder**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A306-2DA, Part 1)

**Purpose**—The fitting of multi-functional prosthetic arms to persons with high-level amputations continues to be a significant challenge to prosthetists and a frequent disappointment to users. In spite of a variety of body-powered and manually-positioned

arm components which have been available for several decades, there are many deficiencies in these components that become all too apparent in high-level fittings. Total arm prostheses which incorporate the few electrically-powered positioning compo-



nents (elbows and a wrist rotator), have not been unconditionally successful, and have introduced a new set of problems.

Based on experiences with prostheses for persons with high-level amputations, this laboratory believes that body-powered or manually-positioned positive-locking components, with their comparative mechanical simplicity, general ruggedness, and lower cost, have not been fully exploited. Arm prostheses which utilize manually-positioned joints (e.g., at the wrist) in conjunction with an above-elbow (AE) or shoulder disarticulation (SD) elbow/prehensor cable control system can often be configured with the same control cable also positioning these components. This configuration has many advantages; most significantly, the cable control utilizes the person's otherwise intact musculoskeletal and sensory systems. Consequently, there is close coupling between the user and the prosthesis, presumably reducing the mental effort required in positioning the prosthesis. Once positioned, the joints are locked in place through some mechanical control.

We believe that the dependency on mechanical linkages to operate the locking mechanisms in these devices limits their effectiveness for the user and complicates the prosthetic fitting. To provide more efficient and versatile control of these components, a simple, modular electromechanical lock actuator is being developed which can be used in conjunction with existing cable-operated elbows and positive-locking wrist components. The principal advantage of the lock actuator is the replacement of the high forces needed to operate the mechanical controls now used with the considerably lower forces needed to operate an electrical switch controlling a motorized actuator. A second advantage is greater facility in placement and configuration of the switch control, over that possible with a cable or lever mechanically linked to the locking pin.

**Progress/Preliminary Results—Modular Electromechanical Lock Actuator.** During the past year, we

have been working closely with the Department of Orthotics/Prosthetics Clinical Service of the Rehabilitation Institute of Chicago in prosthetic fittings involving mechanically-actuated positive-locking components. This close cooperation has enabled us to identify user characteristics and prosthetic configurations in which an electromechanical lock actuator can be of significant advantage over a purely mechanical actuator. The prototype electromechanical actuator previously reported has been fit to the locking mechanism of a Hosmer E-400 cable-controlled elbow in preparation for a trial fitting. A second actuator is being fabricated for use with a U.S. Manufacturing Company (USMC) Rotation Wrist as part of a Robin-Aids-type four-function forearm set-up.

**Positive-Locking Shoulder.** A second component of this project has been an effort to develop a shoulder joint with positive-locking in the plane of flexion/extension. A prototype joint, modified from existing components, has been developed and fit to an individual with a unilateral scapulothoracic amputation. The lock mechanism (mechanical in this initial fitting) of the shoulder was linked in parallel to the locking mechanism of a manually-positioned Otto Bock elbow, and connected to an actuating lever placed at the wrist. Using the contralateral hand and arm, the subject is able to unlock both elbow and shoulder in one motion, reposition the arm, then re-lock both joints. (An electric hand is operated by a figure-of-nine harness connected to a four-position switch.)

**Future Plans—**The design of a locking shoulder joint appropriate to a shoulder disarticulation amputation will be our next objective.

*See page 18 for Part 2 of this study.*

### **Publications Resulting from This Research**

**Positive-Locking Components and Hybrid Fitting Concepts for Persons with High Level Bilateral Arm Amputations.** Childress DS, Krick H, Heckathorne CW, Uellendahl J, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 296-297, 1989.

## [14] Development of Advanced Body-Powered Prosthetic Arms

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A421-DA)

**Purpose**—The primary objective of this work is to design an advanced, body-powered artificial arm. The design criteria include: an adjustable elbow cable excursion to simplify fitting, a cable recovery system which will allow independent elbow and terminal device control (each with full cable actuation), a light-weight and strong structure with a front hinge for high excursion capabilities, and an internal cabling using polymer cable materials for better cosmetics.

**Progress**—*Actuation Linkage. Design of cable/elbow kinematics.* The kinematics of the cable actuation linkage of the elbow has been analyzed. The linkage can be “tuned” to provide almost any cable force to elbow position relationship desired. A conventional body-powered arm has a very non-linear force-position relationship. The maximum cable force is when the elbow is at an angle of 90 degrees and drops rapidly as the elbow angle increases. This can cause positioning problems when the amputee is attempting to position the arm at a high angle. The force-position relationship of the new VA-Utah Arm is more constant and will hopefully (untested as yet) provide better positionability at all elbow angles.

*Cable Path for Terminal Device.* The actuation cable and state changer will be in the humeral section of the arm. This arrangement provides easier cable terminations by not requiring Bowden cable-type housings, but requires that the terminal device cable crosses the elbow joint. This arrangement makes it difficult to have constant terminal device cable length over the range of elbow angles. A simple cable arrangement has been designed that allows only a 0.25-inch cable length change over the range of the elbow angle. This small length change is

easily handled by the cable recovery system.

*State Changer.* The state changer sequentially changes the control of the actuation cable from the elbow to the terminal device when the elbow unlock/lock is changed. A prototype has been built and is undergoing evaluation.

*Elbow Lock.* The work on the elbow lock design is just commencing. It is our goal to have a lock mechanism which can be actuated either by mechanical or electrical drives.

*Structure.* The design of the structure involves the material selection and manufacturing techniques. We are investigating plastics and molding processes in combination with cast and machined metals.

*Polymer Cable Testing.* We are investigating polyethylene fiber cables for use as the control cables for the arm and terminal device. Of interest is the wear and fatigue of the cables when run around pulleys, through cable housings, and rubbing on dry surfaces. We have built a fatigue testing machine which can test the cables over all of the conditions. Approximately half of the tests have been completed.

*Cable Terminations.* One of the main difficulties with the use of polyethylene cables is the problem of attachment to terminations. Simple knots do not hold, and glues will not bond to polyethylene, so it is difficult to make a simple, small, neat termination. We are investigating several alternatives which use a combination of cable chemical treatments and glueing and mechanical gripping of the fibers.

### Publications Resulting from This Research

None reported.



## [15] Functional Biomechanical Characterization and Functional Design Specification: Upper-Extremity Prosthetics

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Sponsor: *National Institute on Disability and Rehabilitation Research*

**Purpose**—The title represents a set of projects within a component of our National Institute on Disability and Rehabilitation Research (NIDRR) funded Rehabilitation Engineering Center in Prosthetics and Orthotics. The projects are part of our effort to develop methods of characterizing upper- and lower-limb prosthetic and orthotic components and devices, and to gain an understanding of the relationship between design characteristics and functional performance. Our upper-extremity prosthetics projects are divided into two areas of investigation: 1) increasing the security of grasp with a prosthetic prehensor; and, 2) improving approach trajectories and alignment of prehension devices.

Within the first area, we are pursuing two lines of work. One is to characterize the types of material currently used to line prehension surfaces and identify those characteristics which contribute most effectively to prevention of slip. The second line of work is the development of a slip transducer to be used in an automatic gripping system adapted for commercial electrically-powered prehensors.

Within the second area, we have three objectives. The first is the development of powered components to extend the spatial envelope in which a prehensor can be *actively* positioned by a person with an above-elbow or higher level of amputation. The second is the development of a computer-based prehensor positioning assessment tool to aid prosthetists in the selection of components for fitting higher-level and bilateral amputations. The third is a combined study of reaching and grasping and of the division of function between the dominant and non-dominant physiological hands. These studies may aid in understanding how characteristics of a prosthetic prehensor influence its utilization.

**Progress/Preliminary Findings**—This report will focus on two of our projects: slip detection for automatic gripping and the computer-based prehensor positioning assessment tool.

*Slip Detection for Automatic Gripping.* A test

fixture and prototype transducers have been constructed to examine the response of the piezoelectric polymer polyvinylidene fluoride (PVDF) to simulated slip vents. It was hypothesized that a composite transducer made up of two closely-spaced sensors would respond to vibrations originating from one or the other sensor (vibrations due to an object sliding over the surface of the transducer) in a differential signal, but would respond to vibrations originating remotely from the transducer (vibrations transmitted to the transducer through its attachment to a substrate) in a common mode.

By exacting fabrication and careful mounting of the prototype transducer, it has been possible to significantly reduce the effect of common mode signals through differential amplification. With the addition of bandpass filtering and threshold detection, it has been possible to differentiate slip vibrations from incidental vibrations in most instances, thereby verifying the feasibility of this approach.

*Computer-Based Prehensor Positioning Assessment.* A computer-based graphical model of a six-degree-of-freedom generic total arm prosthesis has been developed. The model was used to investigate various aspects related to the kinematics of a multi-joint arm in which two joints might be coupled, as in shoulder flexion and elbow flexion in the operation of an above-elbow prosthesis. The model was also used to evaluate methods by which the operator could interact with the model to select and direct its actions.

A second phase of software development has focused on a set of routines capable of determining the functional workspace of a human/prosthesis system. The phrase “functional workspace” is defined as that volume in which the prehensor of the prosthetic arm can be positioned using only movements of the prosthetic joints and joints of the residual limb, including (if they are intact) the joints of the shoulder complex. Determination of the volume and geometric shape and orientation of the



workspace is being considered as one means of comparing the effectiveness of different arrangements of prosthetic components.

A database of clinical fittings and components used in those fittings is being assembled for the next phase of the project—incorporation of prosthetic and physiological parameters into the model.

### Publications Resulting from This Research

**Capacity of the Human Operator to Move Joints as Control Inputs to Prostheses.** Mesplay KP, Childress DS, *Modeling*

*and Control Issues in Biomechanical Systems, American Society of Mechanical Engineers, DSC(12), BED(11):17-25, 1988.*

**Positive-Locking Components and Hybrid Fitting Concepts for Persons with High Level Bilateral Arm Amputations.** Childress DS, Krick H, Heckathorne CW, Uellendahl J, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 296-297, 1989.

**Control Philosophies for Limb Prostheses.** Childress DS, in *Proceedings of the International Seminar Celebrating the 25th Anniversary of the Bioengineering Unit, University of Strathclyde*, Glasgow, Scotland, accepted for publication.

## [16] Quantification of the Functional Capability of Upper Extremity Amputees

**Neville Hogan, PhD**

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**Sponsor:** *National Institute on Disability Research and Rehabilitation; National Science Foundation; Whitaker Foundation; Fairchild Foundation*

**Purpose**—The goal of this project is to develop quantitative techniques for assessment of upper-extremity functional performance, with a particular focus on above-elbow amputees. A computer-controlled prosthesis emulator has been developed. This externally-powered prosthesis can be worn by an above-elbow amputee and operated through any of the usual command channels (e.g., switch control, myoelectric activity, cable pull, etc.). It can be programmed to mimic the behavior of *any* prosthesis—whether an existing device or a proposed new design. It is fully instrumented to provide measurements of all relevant variables (e.g., motions, forces, etc.).

**Methodology**—A wide variety of tasks performed by the upper extremity requires interaction with the environment. Observations of intact and amputee subjects performing functional tasks (including tool use) showed that the upper extremity must frequently operate in the presence of a kinematic constraint—simple examples are opening a drawer or sliding the hand along a tabletop. In general, these tasks cannot be performed without coordinated action of both the natural and artificial segments. Therefore, the ability to coordinate natural and artificial limb segments is of paramount importance. To assess this important functional capability quantitatively, a simple but surprisingly

informative test was devised: turning a crank in a vertical plane.

One of the most important aspects of powered prostheses is the way in which the devices are controlled. To achieve satisfactory coordination of natural and artificial limb segments, it is necessary that the artificial limb respond to the amputee's muscles in much the same way that the natural limb does. A controller that mimics the natural limb's adaptable compliant behavior (technically, its *mechanical impedance*) has been developed.

An important feature of the natural limb's compliant behavior is that it can be adjusted voluntarily (primarily by coactivating opposing muscles) to meet task demands. To understand the relation between myoelectric activity and limb behavior, experimentally-verified mathematical models were developed to predict the natural strategies of antagonist muscle coactivation. One important result is that *the wrong direction of motion* will be predicted from measured myoelectric activity if the adaptable, compliant behavior of muscle is not accounted for. To date, myoelectrically-controlled prostheses have not taken account of this fact.

To test the effectiveness of a "natural controller," measurements were made of the crank-turning performance of a unilateral amputee using the prosthesis emulator, programmed to respond to the amputee in two different ways: 1) the emulator was



programmed to mimic the behavior of the Boston Elbow. Myoelectric signals from elbow flexor and extensor muscles were used in a "velocity controller" to command the speed of movement of the elbow; and, 2) using the same myoelectric signals, the emulator was programmed to mimic the compliant behavior of the natural elbow. In particular, when the amputee coactivated the elbow flexors and extensors simultaneously, the elbow stiffened (as does the natural arm).

**Results**—The amputee's performance using the natural control was significantly better than with velocity control (which is used in both the Boston Elbow and the Utah Arm). Although the amputee could perform the task using the velocity controller, the natural shoulder and artificial elbow frequently opposed one another's action, making the task difficult. In contrast, using the natural controller, the natural shoulder and artificial elbow acted in a well-coordinated synergy.

### Publications Resulting from This Research

**An Emulator System for Developing Improved Elbow-Prosthesis Designs.** Abul-Haj C, Hogan N, *IEEE Trans Biomed Eng* BME-34(9), 1987.

**Quantitative Assessment of the Importance of Elbow Prosthesis Dynamic Behavior in the Performance of Manual Tasks.** Hogan N, Miller C, in *Proceedings of the 10th Annual RESNA Conference*, San Jose, CA, 193-195, 1987.

**Quantitative Functional Assessment of Control Systems for Upper-Extremity Prostheses.** Abul-Haj C, Hogan N, in *Proceedings of the 10th Annual RESNA Conference*, San Jose, CA, 284-286, 1987.

**Co-Contraction of Antagonist Muscles: Predictions and Observations.** Murray WR, Hogan N, in *Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 10:1926-1927, 1988.

**Maintenance of Elbow Equilibrium Through Co-Contraction.** Murray WR, in *Proceedings of the 14th Annual Northeast Bioengineering Conference*, 29-32, 1988.

**Modeling Elbow Equilibrium in the Presence of Co-Contraction.** Murray WR, in *Proceedings of the 14th Annual Northeast Bioengineering Conference*, 190-193, 1988.

## [17] Enhancement of the Variety Village 62 Elbow (VV62)

**Morris Milner, PhD, PEng, CCE; Robert Galway, MD, FRCS(C); Stephen Naumann, PhD, PEng;**

**Ihsan Al-Temen, PEng**

Hugh MacMillan Medical Centre, Toronto, Ontario M4G 1R8

**Sponsor:** Variety Club of Ontario, Tent 28, Toronto

**Purpose**—Our purpose is to enhance the reliability of the VV62 elbow, double the speed, and implement a new harness to make it compatible with the VV812 elbow.

**Progress**—The primary design modification made to enhance the reliability of the VV62 elbow was to stiffen the support for the motor shaft. Additionally, all gears were precision-cut and made from a high-quality steel alloy. The harness was also routed along the inside of the outer housing cover and through the center of the turntable. The harness used on the upgraded VV62 elbow was basically the same as the VV812 elbow harness.

**Preliminary Results**—One prototype has been built with all of the above modifications. This prototype is scheduled for endurance testing. This activity will proceed with the existing motor overdriven at twice its present speed. However, the goal for the production VV62 elbow is to use a customized motor, provided the noise level is shown to be acceptable.

### Publications Resulting from This Research

None reported.

## B. Upper Limb

### 3. Below-Elbow

#### [18] Powered Prosthetic Fingers

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A306-2DA, Part 2)*

**Purpose**—The purpose of this project is to develop externally-powered fingers (including thumb) that can be combined to create a functional, yet cosmetic, partial-hand prosthesis that will preserve the independent motion of the wrist.

The secondary function of this project is to see if powered fingers (or thumb) can be used with amputees who have fingers remaining, and also to examine whether they can be of use in devices for wrist and below-elbow amputations.

**Progress/Methodology**—The fingers are to be the same size as those of an average adult. They are to have either one articulation (metacarpophalangeal [MP] joint) or two (MP and the proximal interphalangeal joint). The performance goals are: 1) each finger is to develop at least 6.0 lbf; and, 2) to have a velocity of 1.0 rad/s or greater. The weight of each finger is not to exceed 2.0 ounces.

As this project has evolved, emphasis has shifted from the concept of each finger as an individual unit to the idea of a total partial-hand prosthesis. A design has been finalized and a prototype partial-hand device has been fabricated.

The feasibility of individually-powered prosthetic fingers arose from the advent of motors only 10 mm in diameter that are small enough to be placed within an artificial finger. Initial tests revealed that the motor was capable of meeting either the speed or the force criterion, but was incapable of meeting both simultaneously.

The principle of synergy was adopted to boost overall performance. In a synergetic system there are at least two motors: one delivers high speed at low force, and the other provides high force at low speed.

The resulting design uses three motors, all 10 mm in diameter with 256:1 gearheads: one each in the thumb, index finger, and middle finger. In order to achieve the maximum pinch force, the thumb motor provides the speed, and the index and middle fingers provide the force.

The drive system for the fingers uses the gear motor mentioned previously along with a drive screw. The actual pinch force per finger is 8.5 lbf using a standard 3-56 screw thread which gives the hand a total gripping force of 17 lbf.

The drive system for the thumb uses the same gear motor in combination with a 3:1 bevel gear set attached to a back-lock mechanism. This provides an angular velocity for the thumb in excess of 2 rad/s and an excursion of 3 inches.

The thumb pivot is inclined at an angle of 45 degrees to the palmar surface. This maintains a cosmetic geometry for the thumb motion while providing a usable width of opening for the hand. The dynamic cosmesis and width of opening considerations for an inclined thumb are dictated by the synergetic design. This requires the thumb to provide all the width of opening while maintaining a dynamically cosmetic geometry.

The power source for the hand is a 9-volt transistor battery; the preferred suspension of the hand is a suction socket. Myoelectric or switch control can be used.

**Results/Future Plans**—The prototype hand that has been built exceeds the dynamic performance requirements of the original specification. However, it is too heavy and too big for clinical applications at present. The next stage in development of the powered-fingers project is to produce a smaller,



lighter version of this prototype; clinical trials will follow.

*See page 12 for Part 1 of this study.*

#### Publications Resulting from This Research

None reported.

### [19] Optimizing Myoprosthetic Management with Microcomputers

Robert Galway, MD, FRCS(C); Stephen Naumann, PhD, PEng; Morris Milner, PhD, PEng, CCE; Martin Mifsud, Dip EEngT; Sheila Hubbard, BScPT, Dip P&OT; Geb Verburg, MA  
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Sponsor: Hospital for Sick Children Foundation, Toronto

**Purpose**—This project is aimed at establishing new strategies and objective standards for the analysis of myoprosthetic operation. Its specific goals are to: 1) develop and test the reliability of an objective test of an amputee's ability to control a myoelectric control system; 2) establish and develop a standard database of an amputee's abilities to operate a myoelectric prosthesis; 3) increase the speed and accuracy of the muscle site location and control system calibration procedures through the development of a microcomputer-based muscle site identifier and control system calibrator; and, 4) evaluate the new myoelectric muscle site identifier and control system calibrator in comparison with traditional methods.

**Methodology**—Two groups of thirty experienced below-elbow amputees (i.e., with six months or more of myoelectric experience) are participating in the project. They are over five years of age and have the commonly-used Otto Bock two-state control system. Thirty amputees have been tested with a computer-based Myoelectric Control Assessment Program (MCAP) to evaluate its reliability and establish a database of prosthetic control measurements. MCAP gives the amputee interactive control of a visual hand stimulus. The goal is to position the fingers at a target area using myoelectric control. Target and hand position, number and duration of events, and elapsed time are recorded by the computer for subsequent analysis. Subjects in this group were asked to visit the Centre on three occasions (i.e., Day 1, Month 1, Month 3) and complete six test sessions on each occasion. A second group of amputees requiring refitting of their prostheses is currently being tested to evaluate the microcomputer-based muscle site identification and

control system calibration procedures. The team is investigating how these procedures affect the operation of the myoelectric control system in comparison to that of the traditional procedures. This group of amputees is seen during normally-scheduled fitting visits.

**Results**—The data derived from the research protocol, as well as the demographic data of the subjects involved in the study, have been handled in the dBase III+ environment. Support programs to facilitate the importation and exportation of data have been written in dBase III command language. This has provided an efficient and powerful means of data manipulation: it assists indexing, sorting, and subset screening. All data were processed with the SYSTAT statistical analysis package. The demographic database will further provide an ongoing database structure for the collection of patient information arising from further clinic encounters. An initial estimate of reliability was obtained by calculating Pearson correlations between the means of pairs of test sessions within and across visits. Correlations between means of eight variables within Day 1 and within Month 1 data indicate that the MCAP test is reliable with correlations ranging from 0.6 to 0.8. Correlations of means across visits give an indication of longer term reliability. These correlations, though somewhat lower, indicate good longer term reliability for the MCAP test.

#### Publications Resulting from This Research

**Microcomputer-Based Myoelectric Assessment System.** Mifsud M, Hubbard S, Verburg G, Naumann S, Galway HR, Milner M, *J Assoc Child Prosthet Orthot Clin*, accepted for publication.

## [20] Improvement of Body-Powered Upper Limb Prostheses

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Our goal is to improve the acceptance and use of body-powered upper-limb prostheses by arm amputees. The objective of this project is to improve conventional arm prostheses by means of: 1) an hydraulic force transmission system to replace the present cable control system; 2) a prehensor which is neither hook nor hand; and, 3) an elbow extension control to eliminate the shoulder harness.

**Progress**—Prototypes of a rotating thumb, a voluntary closing/voluntary opening (VC/VO) prehensor, and of an elbow-extension-controlled prostheses have been made, and are being tested with below-elbow (BE) amputees. Prototypes of hydraulic control systems have been made and laboratory tested, but do not meet the necessary requirements for fitting arm amputees.

**Preliminary Results**—It was found that even though the hydraulic control system is conceptually great, it is difficult to implement inside the prosthesis. Three prototype prehensors, which are neither hook nor hand, have been tested in use with three BE amputees; and three elbow extension control systems with different elbow-latching mechanisms to allow free swing, have been tested with BE amputees. Results are being evaluated.

**Future Plans**—This project concluded on October 1, 1989. Results of the project are being summarized. A final meeting of the advisory committee will be held, recommendations will be made, and a final report will be published.

### Publications Resulting from This Research

**Do We Need a Prosthetic Prehensor Which Is Neither Hook Nor Hand?** LeBlanc M, Parker D, Nelson C, in *Proceedings of the 10th Annual RESNA Conference*, San Jose, CA, 204-206, 1987.

**Making the Case for Body-Powered Upper Limb Prostheses.** LeBlanc M, in *Proceedings of the 10th Annual RESNA Conference*, San Jose, CA, 196-198, 1987.

**New Designs for Prosthetic Prehensors.** LeBlanc M, Parker D, Nelson C, in *Proceedings of the Ninth International Symposium on Advances in External Control of Human Extremities*, 1987.

**Assessment of Three New Designs of Prosthetic Prehensors for Upper Limb Amputees.** Meeks D, LeBlanc M, *Prosthet Orthot Int* 12(1):41-45, 1988.

**Evaluation of a New Design: Body-Powered Upper-Limb Prosthesis Without Shoulder Harness.** Meeks D, LeBlanc M, *J Prosthet Orthot* 1(1):45-49, 1988.

**Survey of Arm Amputees Not Wearing Prostheses: Implication for Research and Service.** Melendez D, LeBlanc M, *J Assoc Child Prosthet Orthot Clin* 23(3):62-69, 1988.

**Use of Prosthetic Prehensors.** LeBlanc M, *Prosthet Orthot Int* 12(3):152-154, 1988.

**Rotary Hand Prosthesis.** Patent applied for: March 21, 1988.

## C. Lower Limb

### 1. General

## [21] Identification of Optimal Amputation Level in Ischemic Limbs

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A419-RA)*

**Purpose**—The aim of this research project is to characterize perfusion in ischemic limbs using quan-

titative thallium-201 scintigraphy with the goal of identifying the level at which an amputation site will



heal well while preserving the longest possible residual limb.

**Methodology**—Following temporary arterial occlusion with a blood pressure cuff applied to each thigh for 5 minutes to induce reflex hyperemia, thallium-201 is injected intravenously. An initial rapid sequence of images provides a radionuclide angiogram of the lower limbs. This is followed by serial 1-minute images for 30 minutes. Three to four hours later, the series of 1-minute images is repeated to show resting perfusion.

Visual inspection of the images shows areas of delayed filling in the flow study, perfusion defects in the images, and which areas are underperfused early, and thus redistribute on the resting images. Time activity curves for regions of the feet and legs for the three phases of the study show marked flattening of the in-flow curves in the radionuclide angiogram in ischemic areas. The early images show an immediate peak and prompt washout in normal areas, and a delayed peak and slower washout in ischemic areas. This tends to support a similar

finding by Lassen, using Xenon-133. The profiles of early and delayed images are also compared. Experience with thallium-201 kinetics in the heart suggests that normally perfused areas should have higher uptake early with washout in the later images, and ischemic areas should have higher uptake in the later images. The latter has been found to be true, but uptake, even in normal areas, has been found to be the same or slightly higher on the resting study. This finding has also been reported recently by another investigator. The reason for this is not clear and may be age related. Based on this analysis, regions of the legs and feet are characterized as either normal, mildly, moderately, or severely ischemic. Amputation is performed without knowledge of the thallium study. The outcome of amputation is compared with the evaluation of perfusion by thallium-201 scintigraphy to determine the level of perfusion at which prompt healing will occur.

#### **Publications Resulting from This Research**

None reported.

## **[22] Development of HLA Class I Transfectants as Suppressor Cell Inducers: A Pilot Study**

**Ernest M. Burgess, MD; John A. Hansen, MD; Michael A. Bean, MD**

Prosthetics Research Study, Seattle, WA 98122; VA Medical Center, Seattle, WA 98108; Fred Hutchinson Cancer Research Center, Seattle, WA 98104; Pacific Northwest Research Foundation, Seattle, WA 98122

**Sponsor:** VA Rehabilitation Research and Development Service (Pilot Project #A982-PA); Pacific Northwest Research Foundation

**Purpose**—As part of the development of a program of tissue and limb allograft research, this pilot proposal was initiated to use the technique of Class I gene transfection of normal human lymphoblastoid cell lines in order to make HLA-defined transfected cell lines for use in studies of immune regulation in humans *in vitro*. The ability to do planned immunizations in humans is limited, if not virtually impossible, and thus *in vitro* assays of lymphocyte interactions are the main means of unraveling the positive and negative signals of immune responses.

Constructing autologous lymphoblastoid cell lines from normal healthy blood donors that express new defined Class I HLA antigens will enable us to test whether or not different Class I HLA antigens in man are able to preferentially induce suppression of the immune response measured by the develop-

ment of allospecific suppressor cells; and, to determine whether or not there is variation in the population of humans in terms of the ability of different individuals to mount suppressor cell responses to a given HLA Class I antigen.

The rationale for these studies is that alloantigen-specific suppressor T cells appear to be important in the establishment of allograft tolerance. In addition, one of the mechanisms through which the beneficial effects of donor-specific transfusion on allograft survival in murine and human models is mediated, is hypothesized to be through the development of these allospecific suppressor T cells. The exact mechanisms and the inducer and target antigens responsible for the development of these cells is not yet known. Identifying which combinations of donor/recipient histoincompat-



ibility induce allospecific suppressor cells should improve the success of allografting tissue across major histocompatibility barriers.

**Methodology**—Previously cloned HLA-A2 and HLA-B27 histocompatibility antigen genes are inserted into a plasmid vector (pHEBo) which contains the EBV origin of replication sequence, and a gene for conferring drug resistance to hygromycin-B. This vector is then inserted into EBV-transformed lymphoblastoid cell lines by the method of electroporation. The lymphoblastoid cells are then grown out in hygromycin-B to select resistant cells, which by definition, will have taken up the plasmid for drug resistance and also the HLA-A2 or -B27 cloned DNA.

Growing cells are cloned, grown up in hygromycin-B and the expression of the new HLA antigen confirmed by the use of antibodies binding to the new antigen specificity when analyzed on the fluorescence-activated cell sorter. After the cells are grown up in quantity, a portion of these cells are cryopreserved; growing cultures will be a source of cells to be used as stimulators and target cells in assays of *in vitro*-generated suppressor cells.

Such cells will be used both as stimulators of fresh blood mononuclear cells from the individuals from which the cell lines were derived, and used in panels of stimulator cells where normal blood lymphocytes have been primed with defined stimulator cells. Then they will be monitored for their

ability to suppress the responses against matched cell lines containing no or new HLA antigens.

**Progress/Preliminary Results**—A number of normal individuals have now been carefully characterized as to their HLA phenotype, and lymphoblastoid cell lines from these individuals are being derived by EBV transformation using the Marmoset B95-A-8 cell supernatant. We are currently adapting the gene transfection technique to our lab using methodology developed by Dr. Daniel Geraghty in Dr. Hansen's lab. One such cell line from a normal individual obtained from Dr. Hansen's laboratory has now been successfully transfected with HLA-B27 and has been grown up in sufficient cell numbers for use in the *in vitro* generation/target cell assay. This same EBV transformed lymphoblastoid cell line so far has been resistant to transfection of HLA-A2. The reasons for this are unknown at present.

**Future Plans/Implications**—In addition to preparing panels of EBV transformed lymphocytes from well HLA-defined individuals for transfection with defined HLA antigens, we are also recruiting families consisting of young adults where both parents are available and willing to participate in the study so that we may examine the effect of *in utero* exposure to HLA antigens as it affects the outcome of development of suppressor cells.

#### **Publications Resulting from This Research**

None reported.

### **[23] Development of a Model for Modified Transfusion Enhancement of Grafts: A Pilot Study**

**Ernest M. Burgess, MD; Michael A. Bean, MD; Rainer Storb, MD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Pilot Project #A980-PA); Pacific Northwest Research Foundation

**Purpose**—As part of the development of a program of limb and tissue allograft research, this pilot project was initiated to develop and adapt a dog model for the assessment of the ability of modified blood product transfusions to prevent sensitization and to produce tolerance to subsequent grafts. This bone marrow transplant model in the dog, where

animals are given blood products prior to bone marrow from the donor of the blood products, has been demonstrated to be a very sensitive model for the detection of sensitization/tolerance induction. The rationale for these studies is that pre-transplant donor-specific transfusions facilitate/enhance solid organ allografts in both rodents and humans, and



blood products which have been treated/modified to inactivate class II HLA (major histocompatibility complex) stimulatory activity of the “passenger” leukocytes appear to be preferentially tolerizing/nonimmunogenic in conditioning for subsequent transplantation. UV-B and -C irradiation has been previously shown in the mouse and rat *in vivo* and with human lymphocytes *in vitro* to inactivate the ability of class II antigens to stimulate an alloimmune response. In the mouse and rat, such treated blood products immunologically facilitate organ allografting. In addition to UV-B or -C treatment, heat inactivation of blood products at 45 degrees Centigrade for 45 minutes accomplishes a similar effect in that it inactivates the ability of the “passenger” leukocytes to stimulate *in vitro* in mixed lymphocyte culture.

In published preliminary *in vivo* experiments in the rat, such heated products enhance allograft survival. There are a number of practical drawbacks in attempting to UV-B or -C treat whole blood preparations and the possibility of UV-C treatment reactivating/mutating contaminating virus. Thus, we wish to determine whether or not heat-inactivated whole blood will produce a blood product that is at minimum capable of preventing sensitization and hopefully capable of inducing tolerance to foreign transplant antigens.

**Methodology**—Transfusions of 50 cc of whole blood or platelet preparations containing leukocytes are given intravenously to the recipient dogs 24, 17, and 10 days before transplant. On day 0, bone marrow is transplanted from the donor of the blood product into the recipient of the blood product. The recipient is whole-body gamma irradiated for immunosuppression prior to bone marrow transplant. Animals are maintained in Intensive Care for approximately 5 days and provided leukocyte support therapy. Engraftment is monitored by white blood cell counts and engraftment usually happens by day 10 to 14 post-transplant. In addition to blood counts, engraftment or lack thereof is documented by bone marrow biopsies and by autopsies. The effect of modified transfusions may be evaluated in two different histoincompatibility settings. The first is with DL-identical littermates who differ by minor histocompatibility antigen loci and in DLA-

nonidentical dogs who differ by both major and minor transplantation antigen loci.

**Progress/Preliminary Results**—In prior work in Dr. Storb’s laboratory, 25 out of 25 DLA-identical littermate dogs transfused with whole blood three times during the six weeks prior to bone marrow transplant from the donor of the transfusion product, rejected the bone marrow transplant, demonstrating that they were sensitized by the transfusions. Transfusion of donor-specific blood that had been UV-C inactivated eliminated the sensitization and allowed ten out of ten dogs to accept the bone marrow graft. We have now established that the leukocytes contained in platelet preparations can be inactivated with between 408 to 612 mJ/cm<sup>2</sup> of UB-V irradiation (predominant emission 310 nm). Four out of four dogs receiving three transfusions of such UV-B irradiated blood products have successfully engrafted. We have also established that 45 minutes of 45 degrees C treatment of blood inactivates the “passenger leukocytes.” Of ten dogs receiving heat-inactivated whole blood preparations, one dog died of sepsis at day 9 and is not evaluable. Eight of nine evaluable dogs who received three transfusions of heat-inactivated gamma-irradiated whole blood engrafted and, a concurrent control of four dogs who received three untreated whole blood transfusions prior to bone marrow transplantation from the donor of the blood, rejected their grafts, thus confirming the historical control data.

**Future Plans/Implications**—These preliminary data suggest that the simple procedure of heat inactivation plus gamma irradiation of blood products produces preparations which are preferentially non-sensitizing and possibly could be tolerizing. Additional dogs will be entered into this protocol using DLA identical dogs to clearly establish that these preliminary data are correct. We will then move to the DLA-nonidentical major histoincompatible donor/recipient combinations to evaluate the lack of sensitization and potential for tolerance induction of these modified blood products.

#### **Publications Resulting from This Research**

None reported.



## **[24] National Program for Automated Fabrication of Mobility Aids: Eastern Region**

**Hans R. Lehneis, PhD, CPO; Vern L. Houston, PhD, CPO; Carl P. Mason, MSBE; Edward J. Lorenze, MD;  
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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A514-DA)*

**Purpose**—The National Program for the Automated Fabrication of Mobility Aids (AFMA) is a collaborative research and development project being conducted by the Prosthetics Research Study (PRS) in Seattle, WA, the Prosthetics Research Laboratory at Northwestern University (NU-PRL) in Chicago, IL, and the New York Department of Veterans Affairs Medical Center—New York University Medical Center (DVAMC-NYUMC) in New York, NY. The purpose of this program is to conduct clinical, developmental testing of the computer-aided socket design and computer-aided manufacturing (CASD/CAM) systems for below-knee (BK) prosthetics under development at: 1) the University College London (UCL) Bioengineering Center (currently being marketed by Nutem, Ltd., and Applied Bioengineering Technology, Ltd.); and, 2) the University of British Columbia-Medical Engineering Resource Unit (UBC-MERU) (currently being marketed by Shape Technologies, Inc.). Clinical tests with a statistically representative sample of BK amputees are being conducted using these systems: 1) to identify those areas/components of the systems that are fully developed, those that require further design refinement, and those in need of further research and development; 2) to identify categories and characteristics of patients that can be successfully fit using the socket design methods implemented in these systems, and those (if any) that cannot; 3) to obtain quantitative data regarding physiological, biomechanical, and prosthetics parameters of BK amputees for enhancement of CASD socket design principles; and 4) to demonstrate the feasibility and benefits of AFMA technology in prosthetics, and to provide a limited introduction of this technology to practicing prosthetists and other rehabilitation and health care professionals.

**Progress**—Commercial prototypes of the UCL CASD/CAM software and equipment were ordered from Nutem, Ltd., in England, and installed at the NYU Medical Center during November 1988 to

March 1989. This equipment has subsequently been re-installed at the NY DVAMC for easier and more expedient integration with the NY DVAMC STAMP Clinic and the DVAMC Prosthetics and Sensory Aids Service Orthotics Laboratory patient care services.

To date: evaluations, measurements, castings, and digitizations have been performed; CASD sockets designed for; and check socket fittings conducted on 19 BK amputees. A number of software and hardware problems have been encountered, diagnosed, and analyzed. Solutions have been obtained, and most of the recommended firmware and software changes have been instituted by the UCL Bioengineering Center and Nutem, Ltd. Clinical testing at the NY DVAMC/NYUMC is again proceeding. Data from these clinical trials, as well as data from the trials being conducted at PRS and NU-PRL, is being compiled in a computerized relational database management system in New York for subsequent analysis.

Clinical testing of the UBC-MERU CASD/CAM system marketed by Shape Technologies, Inc., has yet to begin because of DVA procurement delays. Work on interfacing the UBC-MERU CASD system to the UCL/Nutem numerically-controlled carver is underway, however.

**Future Plans**—A set of specifications for a photoreflexive, laser-based, optical digitizer for profilogrametric characterization of limb and stump spatial geometry and surface topography for BK prosthetics CASD/CAM system input has been developed, and a prototype procured from Cyberware Laboratory, Inc. Software is currently being developed to interface the Cyberware optical digitizer with the UCL/Nutem and UBC-MERU/Shape Technologies CASD/CAM systems. When this is completed, clinical testing of the optical digitizer will be performed, and a comparison of direct optical digitization results with the current method of electromechanical digitization of



undistorted, plaster wrap casts of amputees' stumps will be made.

#### Publications Resulting from This Research

None reported.

### [25] National Program for Automated Fabrication of Mobility Aids: Central Region

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A521-DA)

**Purpose**—The Prosthetics Research Laboratory of Northwestern University/VA Lakeside Medical Center (NU/VALMC) in Chicago—in collaboration with the Prosthetics Research Study (PRS) in Seattle, and the VA Medical Center in New York City—is involved in the Program for Automated Fabrication of Mobility Aids (AFMA). This program is a cooperative clinical study of computer-aided design and computer-aided manufacturing (CAD/CAM) of sockets for below-knee prostheses. The equipment and techniques are primarily those developed at the Bioengineering Centre of the University College London (UCL), although we will soon receive the CANFIT system developed at the Medical Engineering Resources Unit (MERU) of the University of British Columbia in Vancouver. The objective of this project is to obtain quantitative clinical data to determine the efficacy of the present CAD/CAM equipment and methods, and to uncover possibilities for its refinement and improvement.

**Progress**—The necessary AFMA CAD/CAM equipment arrived this year and our system is fully operational. We have fitted twenty subjects with considerable ease and accuracy. Not all of the subjects have satisfied the requirements of AFMA subject selection; however, we feel the initial extra experience gained from fitting a variety of subjects is important in order to give us an understanding of the actual and potential benefits of computer-aided socket design, using the UCL software and system. We are on schedule with the work, as described in our original proposal, and feel that it can be completed on time. We have invited other prosthetists to participate in the AFMA program and several prosthetic laboratories have responded positively.

In general, we find the system to be very serviceable. This is not to say that the system is perfect or that there have been no problems. We have had some problems in becoming operational, but most of these have been overcome.

**Preliminary Results**—Our experiences, although admittedly limited, have led to several generalizations. For example, we have found several aspects of fitting below-the-knee amputees by computer design techniques to be considerably easier than when using conventional prosthetic techniques. A few CAD/CAM fitting observations that we feel are important are: 1) The system enables one to design definitive sockets with respect to the number of ply. With the UCL software, we feel confident that each diagnostic socket will be in the one-ply fit range. The software allows us to increase or decrease the size of the socket with reasonably accurate predictions of the resulting socket size; 2) the UCL software provides what we term “controlled modification techniques.” Conventional prosthetic modifications make measuring build-ups and reductions very time-consuming and equally difficult to return to the previous condition of the socket. The UCL software not only makes accurately measured rectifications, it records them for future analysis; 3) the software of the system is simple, straightforward, and adaptable to many below-knee residual limb shapes; and, 4) the system records both the socket shape and the history of socket modifications. These records are useful for future reproduction of existing sockets, or for evaluation and analysis.

**Implications**—These points indicate a few significant advantages that the CAD/CAM system will provide to persons with amputations and to their



prosthetists. Our experiences have been, in general, very positive. Further experience, coupled with continued modifications of the software, will provide more areas in which the technology can improve existing techniques.

During the July, 1989 AFMA meeting, the collaborating AFMA centers agreed on several pro-

ocols so that data obtained by the different centers can be united into a scientifically sound, definitive report.

#### **Publications Resulting from This Research**

None reported.

### **[26] National Program for Automated Fabrication of Mobility Aids: Western Region**

**Ernest M. Burgess, MD**

Prosthetics Research Study, Seattle, WA 98122

**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A504-DA)*

**Purpose**—Prosthetics Research Study (PRS) participates in the National Program for the Automated Fabrication of Mobility Aids (AFMA). This is a collaborative effort with investigators at Northwestern University and the Bioengineering Service, VA Medical Center, New York, NY. The purpose of this effort is to jointly assess, develop, and improve the emerging computer-aided design and manufacturing technologies which may be used in the fabrication of mobility aids. The National AFMA program encompasses several different research and development projects.

**Progress**—Machinery for fabrication of AFMA sockets has been obtained and is in daily use. A device for shape-sensing by digital measurement of residual limb casts has been developed at PRS. We have also supplied similar digitizers and/or plans to the other National AFMA Program centers. In November of 1988, a laser shape digitizer from Cyberware Laboratories was tested at PRS. Laser-scanned residual limbs were used as the basis for AFMA sockets. This proved to be a workable alternative to the electro-mechanical cast digitizer.

During the past year, PRS has initiated the AFMA Clinical Demonstration to begin acquiring clinical experience with this new technology. The AFMA clinical demonstration includes both research subjects seen at PRS and subjects included through the AFMA Outreach Project. The AFMA Outreach Project included the patients of private prosthetists throughout the country and 10 VA

Medical Centers (VAMC) designated by the VA Prosthetic and Sensory Aids Service.

In our most recent tabulation, 146 subjects (73 percent veterans) have evaluated 365 below-knee AFMA sockets. As hoped, the large-scale demonstration has illuminated deficiencies and strengths of systems used. The size of the AFMA clinical demonstration is significant in that it represents the largest known experience in using this new technology. It also simulated the production conditions in a large clinical service such as the VAMC system. Information relating to medical histories, prosthesis design, and use are stored in a related database. A comprehensive review of this project and analysis of the database collected is in progress. Sixteen subjects seen at PRS have been included thus far. Our findings have been consistent with those of the outreach subjects. One significant case resulted in the provision of a prosthesis in 1 hour and 55 minutes from the arrival of the subject in our labs. This is especially dramatic because there had been no prior special preparation.

Beginning March 1, 1989, PRS began development of a more flexible software platform for all AFMA projects. As more experience has been gained in the use of existing AFMA software, we have been able to identify the aspects that we would most like to improve. The PRS/VA AFMA software dubbed ShapeMaker, is intended to provide an easy-to-use "toolbox" for manipulating all types of anatomical shapes with user (not programmer) definable modes of manipulation. With this freedom



in hand, we hope that it will be easier for those who already know how to create successful mobility aids to create usable computer tools. The ShapeMaker software has been used to provide prostheses for 20 amputees.

**Future Plans/Implications**—In the coming year, PRS will participate in a collaborative trial of the University College of London Computer-Aided Socket Design (UCL CASD) system. A joint subject data collection protocol has been completed and will be implemented by the three AFMA centers. The collaborative trial will result in a joint report by the three centers. The PRS/VA software will be made as new developments are incorporated.

The development of AFMA is being described as a “revolution in a profession.” While we continue to pursue this study as an experimental research project, it is proceeding at a pace indicating that technology transfer can be carried out effectively in the near future.

#### **Publications Resulting from This Research**

**Rectification Maps: A New Method for Describing Residual Limb and Socket Shapes.** Sidles JA, Boone DA, Harlan JS, Burgess EM, *J Prosthet Orthot* 1(3):149-153, 1989.

**Automated Fabrication of Mobility Aids: Clinical Demonstration of the UCL Computer Aided Socket Design System.** Boone DA, Burgess EM, *J Prosthet Orthot* 1(3):187-190, 1989.

## **[27] Clinical and Laboratory Study of Amputation Surgery and Rehabilitation**

**Ernest M. Burgess, MD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A092-5RA)

**Progress**—During the past year, Prosthetics Research Study (PRS) investigators have completed the VA/Seattle Prosthetic System. This consists of the low-profile, energy-storing SEATTLE Foot, the SEATTLE Shank-Ankle unit, the SEATTLE Alignment-Connector, and the below-knee socket, designed and fabricated by automated means using VA/Seattle software written by us. Cosmesis for this prosthesis is also an outcome of PRS research. This limb is now available and is being used in selected VA Medical Centers. Its release for general use and commercialization is underway.

Wound healing studies continue, with specific interest in skin viability. Present activity involves the micro-wound study, the use of magnetic spectrometry as an experimental tool to extend our knowledge about skin metabolism, and a continuing statistical observation of the relationship of objective tests (in particular, transcutaneous gas measurements) as it relates to the clinical healing of amputations at various levels in the lower limb. TcPO<sub>2</sub> measurements, pioneered by this laboratory, have gradually become the accepted “goal standard” for laboratory assay of skin viability. A study is underway, in collaboration with consultants from the trauma

service at the Harborview Medical Center (HMC) and VA Medical Center (VAMC), Seattle, to delineate rules for decision making as to when to amputate, or when to attempt salvage, immediately or early following severe limb trauma. Guidelines for patient management are critically needed both in the civilian and military sectors. Spectacular advances in limb reconstructive techniques obscure previously accepted decision making. The availability of these techniques, as well as the presence of sophisticated amputee services at both HMC and VAMC, Seattle, provide an excellent research base for this study.

Immediate post-surgical amputee management is being revisited in the light of the availability and experience using variants of the original and standard immediate post-operative procedure (IPOP) system developed by this research unit over the years. These variations include controlled environment methods using air-splints and newer rigid cast materials.

The Prosthetics Research Study continues to be supportive of the STAMP activities at VAMC, Seattle. This includes participation in educational programs.



**Future Plans**—Research into the knee-disarticulation and above-knee level prostheses is now progressing. CAD/CAM sockets will be designed and fabricated by computer control. We will also write the software for this technique.

### Publications Resulting from This Research

**Relationship Between Transcutaneous Oxygen Tension, Ankle Blood, Pressure, and Clinical Outcome of Vascular Surgery in Diabetic and Nondiabetic Patients.** Wyss CR, Robertson CL, Love SJ, Harrington RM, Matsen FA, *Surgery* 101(1):55-62, 1987.

**Reliability of Transcutaneous Oxygen Tension (TCPO<sub>2</sub>) Measurements in Elderly Normal Subjects.** Olerud J, Pecoraro R, Burgess EM, McKnight B, Wyss C, Reiber G, Matsen F, *Scand J Clin Lab Invest* 47:535-541, 1987.

**Transcutaneous Oxygen Tension as a Predictor of Amputation Success.** Wyss CR, Harrington RM, Burgess EM, Matsen FA, *J Bone Joint Surg* 70-A(2):203-207, 1988.

**Amputations and Prosthetics.** Burgess EM, Hittenberger DA, Gold JJ, in *Principles of Orthopaedic Practice*, 1(24):362-363, Dee, Mango, Hurst (Eds.), New York: McGraw-Hill Book Company, 1989.

**Knee Disarticulation and Above-Knee Amputation.** Burgess EM, in *Lower Extremity Amputation*, 13:132-146, W. Moore, M. Malone (Eds.), Philadelphia: W.B. Saunders Company, 1989.

### Patents

**Prosthetic Ankle (SEATTLE Ankle),** Patent Number: 4,792,340; Date of Patent: December 20, 1988.

**Intrinsic Alignment Device** (for lower limb prostheses); Patent applied for: 1988.

## [28] Development of a Limb Allograft Model for Graft Enhancement Studies: A Pilot Study

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**Sponsor:** VA Rehabilitation Research and Development Service (Pilot Project #A981-PA); Pacific Northwest Research Foundation

**Purpose**—As part of the development of a program of tissue and limb allograft research, this pilot study was instituted to develop the rat hindlimb allograft model to be used to study methods of immune suppression/tolerance induction to improve graft outcome. The immediate goal is to establish a rat colony and develop the *in vitro* cellular immune assays to measure alterations in cellular immune responsiveness and to develop the surgical capability for performing the rat hindlimb allograft.

**Methodology**—Mixed lymphocyte culture reactivity, T-cytotoxic assays, and limiting dilution analysis for evaluation of cellular-immune responses are being adapted from those techniques used in man and in other rodent systems. The immunosuppressive drugs, cyclosporine and FK506, a new immunosuppressive drug, along with both modified and unmodified donor-specific transfusions, will be used to develop protocols for immunosuppression/tolerance induction prior to allografting. The modifications of blood products that will be used to inactivate “passenger leukocytes” will be heat inactivation and UV-B irradiation. Hindlimb allografts are constructed using the standard surgical tech-

niques. For example, both donor and recipient limbs are amputated at mid-femur, under general anesthesia. The donor femur is then joined to the recipient site with 4.0 stainless steel suture by placement through both femurs at perpendicular angles. Stay sutures are placed through a few dorsal and lateral muscle groups. The femoral artery and vein are anastomosed end-to-end with interrupted 10.0 monofilament nylon on a 70- $\mu$  needle. Both sciatic and femoral nerves are repaired with four 10.0 interrupted sutures. The remaining muscle groups in the thigh are approximately with interruptible 4.0 absorbable sutures. Lastly, the recipient skin envelope is closed around the ankle by running 3.0 absorbable sutures. Rejection of the allografted limb is evaluated by two methods: 1) limb allografts are observed daily for visual signs of rejection such as erythema, edema and eschar-necrosis of the dorsum of the foot; and, 2) the temperature of the limb is measured daily with a needle thermistor. A 5 degree decline is defined as rejection end-point. Histology is also examined.

**Progress/Preliminary Results**—Representative rat strain combinations have been procured, including



Lewis (LEW, RT-1<sup>1</sup>), Lewis × Brown Norway (LBN, RT-1<sup>1+N</sup>), ACI (RT-1<sup>a</sup>), and PVG (RT-1<sup>c</sup>). We are establishing the tissue culture conditions, including serum types and cell concentrations necessary to perform *in vitro* mixed-leukocyte culture and limiting-dilution analyses. In addition, we have recruited Hidenao Kuroki, M.D., a microsurgeon from the Hiroshima University School of Medicine, who has had prior experience in the rat hindlimb allo- and auto-graft surgical procedures and immunosuppressive protocols using cyclosporine and FK506.

**Future Plans/Implications**—We will now begin to test the effects of donor-specific transfusions alone,

both modified by heat and unmodified on their ability to affect alloresponsiveness of recipient rats. Then we will study protocols combining transfusion in conjunction with cyclosporine and/or FK506 for augmentation of the immunosuppressive effects prior to transplanting. First we will study skin allograft survival as a measure of outcome to develop the optimal immunosuppressive protocols. Then we will study allografting of hindlimbs in these immunosuppressed animals.

#### **Publications Resulting from This Research**

None to date.

### **[29] Circulatory and Mechanical Response of Skin to Compression Loading**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A067-3RA)

**Purpose**—The purpose of this study is to investigate how compression loading of skin produces local ischemia, and how different mechanical properties of the skin and underlying tissues affect this relationship. The restoration of gait in amputees requires loading areas of skin that do not normally sustain weight-bearing loads and that may already be at risk. Many factors contribute to damage caused by external loading, but the primary cause is reduced blood flow and drainage, resulting in reduced delivery of oxygen and nutrients to the tissue and accumulation of waste products. The response to loading will depend upon the mechanical properties of the skin, subcutaneous tissues, and underlying muscle or bone.

**Methodology**—The experimental method utilizes Radiometer E5242 transcutaneous partial pressure of oxygen (TcPO<sub>2</sub>) sensors to monitor the status of the cutaneous circulation. Previous investigations in our laboratory have shown that TcPO<sub>2</sub> is a useful predictor of amputation wound healing in patients with peripheral vascular disease (PVD). Loads are applied directly to the TcPO<sub>2</sub> sensor by a portable load application system and measured by a Sensotec

Model 31 load cell. Skin displacement is measured by a Schaevitz 500DCD linear variable differential transformer (LVDT).

The average applied pressure is calculated from the applied compression load and the contact area of the TcPO<sub>2</sub> sensor at the skin surface ( $2.8 \times 10^{-4} \text{ m}^2$ ). TcPO<sub>2</sub>, applied load and skin displacement are monitored continuously during the experiment.

**Progress**—We investigated skin over the anterior crest of the tibia and over the tibialis anterior muscle (TAM) 12 centimeters distal to the patella approximating the usual below-knee amputation level in 12 younger normal human volunteers (ages 25-43, average 31), 6 older normal volunteers (ages 62-74, average 66), and 10 older PVD patients (ages 54-80, average 66).

A range of pressures from 0 to 150 mmHg was applied and the TcPO<sub>2</sub> allowed to stabilize for 3 minutes at each load. The load was then removed and the TcPO<sub>2</sub> allowed to return to baseline value. Ankle systolic blood pressures were measured with a Doppler flow sensor and ankle pneumatic cuff. The TcPO<sub>2</sub> values were plotted against the applied pressure. Regression analysis was used to calculate

the pressure and displacement at which  $TcPO_2$  reached zero ( $TcPO_2=0$ ). Any additional pressure beyond this level will begin to produce local ischemia. The skin displacement at  $TcPO_2=0$  is an indication of the mechanical compliance of the skin and underlying tissues. To compare mechanical properties over muscle and bone, a separate data file made at a sampling rate of 25 Hz for the 150 mmHg applied pressure loading is used to plot applied pressure versus displacement.

**Preliminary Results**—The skin over bone showed a significantly different load-deformation relationship than the skin over muscle in all subject groups. Initial stiffness for applied pressures less than 20 mmHg over bone was 2.5 times stiffer than skin over muscle in the young normal group. For applied pressures greater than 40 mmHg, skin over bone was seven times stiffer than skin over muscle. Similar results are found in the older subject groups. The resting  $TcPO_2$  values for the skin over muscle and

the skin over bone were not significantly different for all the subjects (59 SD 17 mmHg as compared to 60 SD 8 mmHg for young normals, 53 SD 7 versus 44 SD 4 for older normals, 50 SD 19 versus 51 SD 18 for PVD patients).

The average ankle/arm index (blood pressure ratio) for the young and old normals was 1.0, and 0.40 for the PVD patients. The applied pressure at which the  $TcPO_2$  reached zero was significantly greater for skin over muscle than for skin over bone. The displacement at which  $TcPO_2$  reached zero was significantly more in skin over muscle than in skin over bone (5.6 SD 1.0 mm versus 1.1 SD 0.3 mm in young normals, 6.3 SD 2.1 mm versus 0.7 SD 0.4 mm in older normals, 4.1 SD 2.1 versus 0.3 SD 0.2 mm in PVD patients).

#### **Publications Resulting from This Research**

**Circulatory and Mechanical Response of Skin to Loading.** Sangeorzan BJ, Harrington RM, Wyss CR, Czerniecki JM, Matsen FA, *J Orthop Res* 7:425-431, 1989.

### **[30] Prosthetic Feet: A Comparative Study**

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**Sponsor:** *Commonwealth Department of Veterans' Affairs, Australia*

**Progress**—Continuing the project reported last year, an additional eight prosthetic feet were tested for mechanical capabilities of storage and release of energy in the sagittal plane. In addition, all fifteen types of feet were tested for eversion deflection characteristics, with the same setup used for testing dorsiflexion characteristics.

**Results**—The feet were tested for percent of energy-storing potential, energy return efficiency, and stored energy returned. The following feet are listed in energy-return-efficiency order: Quantum Green; Quantum Black; FLEX; SACH Kingsley No Toe; SACH Kingsley With Toe; SEATTLE; SAFE; Multiflex; Quantum Blue; Dynamic-Fuss; SACH Otto Bock No Toe; Carbon Copy; Sten; SACH Otto Bock With Toe; and Greissinger.

The deflexion characteristics in the coronal plane produced some surprising results. A number of solid ankle feet such as the SEATTLE, the SAFE, and the Otto Bock SACH without toes demonstrated characteristics similar to those of multiaxial feet. The FLEX Foot is completely rigid and does not absorb shocks in the coronal plan.

A pamphlet summarizing results and giving prescription criteria for prosthetic feet was distributed to prescribers and prosthetists accredited on the Australian Commonwealth Free Limbs Scheme.

#### **Publications Resulting from This Research**

None reported.



## [31] Functional Biomechanical Characterization and Functional Design Specification: Lower-Extremity Prosthetics

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Sponsor: *National Institute on Disability and Rehabilitation Research*

**Purpose**—The goal of this effort is to develop a more comprehensive quantitative scientific understanding of the relations between the mechanics of walking, functional performance, and design characteristics of prosthetic components composing lower extremity prostheses. It is intended that this new knowledge will be utilized during exploration of prosthetic design concepts.

The design process for prosthetic components is typically directed by subjective impressions, with indicators of success often being based on market results, rather than quantitative measures which relate to functional performance. Expansion of prosthetic component alternatives, many of which are accompanied by claims of superior function, has resulted in a blurring of the prescription process, rather than focusing it, and facilitating successful outcome.

A forum, in which the relative merits of component function can be compared in a quantitative way, would be useful. An appropriate forum is thought to be mathematical models, which would have not only the potential for allowing the state of a component to be established objectively with respect to a particular function, but the state of a particular component relative to a function can be established within the context of the rest of the parts which compose the amputee-prosthesis system. Current research efforts are toward the development and testing of mathematical models which relate the mechanical characteristics of the prosthesis to quantitative measures of its functional performance during amputee activity. We have chosen to focus on providing a means for relating the mechanical properties of the prosthetic system to the energetics of ambulation, accommodation to changes in loading, and aspects of controlling the prosthesis through controlling joint mechanics.

**Progress/Implications**—Significant progress has been made toward completion of our capability for

making high-quality biomechanical measurements. Our motion analysis equipment (CODA-3) still does not yet meet our standards, but we have continued to improve it, and believe we can complete improvements so that it will perform satisfactorily by the end of the coming year. We have obtained a second CODA-3 unit and are currently in the process of modifying and integrating the two CODA systems, thereby increasing the number of light planes. We hope this arrangement will enable us to always keep track of eight markers and increase the accuracy of the measurements through redundancy.

The construction of a raised walkway with metal walking surface and two force plates, has been completed. A system that facilitates transduction of temporal foot contact information through use of the conductive walkway is nearing completion. Desirable design features of this system are the absence of any type of “umbilical” constraint on the subject during walking trials, and the requirement of only one metal contact at each location where a “contact event” is to be monitored.

We can now routinely overlay quantitative data with video images in real time or through post-processing. This video user interface has the potential for increasing our understanding of the relationships between subjective information (in visual observations) and objective biomechanical data.

An investigation into aspects of lower-limb compliance during normal human walking is underway. The results of this study have the potential to help us better understand the issues of compliance in walking, and can lead to a better understanding of compliant prosthetic legs. It may also assist in prosthesis design specifications.

An investigation of control issues involved in hip-disarticulation walking and above-knee walking is proceeding. The focus of this work is on how the inability of the amputee to directly influence the torques that are applied at the prosthesis' joints,



results in limiting direct control prosthetic step length and swing time.

#### Publications Resulting from This Research

None reported.

## C. Lower Limb

### 2. Above-Knee

#### [32] Optimization of Amputee Prosthesis Weight and Weight Distribution

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A349-RA)*

**Purpose**—Gait studies of the above-knee (AK) population have demonstrated reduced velocity and increased oxygen ( $O_2$ ) consumption relative to the normal population. The goal of this project is to determine the effect of changes in prosthesis mass and mass distribution on gait efficiency in AK amputees in order to define an optimal prosthesis weight configuration.

**Methodology**—Four male subjects (58 to 68 years of age, 44-50 years post-amputation, traumatic cause, unilateral) were fitted with a "light-weight" (2.2 kg) prosthesis utilizing a "Teh Lin" graphite single-axis knee, a carbon fiber pylon, and a SACH foot.

Testing consisted of two sessions: 1) measures of  $O_2$  consumption and walking velocity in a 170-foot hallway; and, 2) measures of kinematic, kinetic, and temporal gait characteristics on a 30-foot walkway. Subjects walked at self-selected speeds with the unweighted limb and with the following load configurations: 1.70, 2.84 and 3.97 kg positioned on the prosthesis 17, 25, and 33 cm distal, and 7 cm proximal to the knee axis.

For measures of oxygen consumption, the subject walked for 4 to 5 minutes to achieve steady-state before exhaled air was collected for one minute as the subject continued walking. Volume expired and percent oxygen were measured to derive metabolic energy expenditure. To measure kinematic parameters, rate gyroscopes and hot-film anemome-

ters were attached to the prosthetic leg to calculate shank and thigh linear and angular velocities. Vertical and antero-posterior ground reaction forces were recorded for the prosthetic leg during stance phase. Gait symmetry was evaluated from measures of swing-phase and single-limb support duration. Two measures of mechanical work, one based on power developed across the joints, and one based on changes in the energy of body segments, were calculated to investigate their usefulness as predictors of metabolic energy expenditure.

**Progress/Preliminary Results**—All four subjects have completed the described protocol. Multifactor analysis of variance was performed for the oxygen consumption results and indicated that subject, added mass, and mass location have a significant ( $\alpha=0.05$ ) effect on energy use while factor interactions were not significant. Regressions relating metabolic energy expenditure to a linear combination of added mass, mass location and either derived measure of mechanical energy were examined; all variables were rejected as predictors of metabolic energy expenditure at a 0.05 significance level. In addition, the study demonstrated: 1) oxygen consumption decreased with addition of weight to the prosthetic shank relative to the unweighted limb; 2) trials with added mass of 1.70 kg resulted in less metabolic energy expenditure than trials with either 2.84 or 3.97 kg of added mass; 3) the 17 and 25 cm



locations were the most energy-efficient and were not statistically different from one another; 4) added mass location, but not added mass magnitude, influenced free-walking velocity. Locations of 17 and 25 cm maximized free-walking speed; and, 5) subjects demonstrated increased swing-phase and single-limb support symmetry as velocity increased, and with the weighted versus unweighted limb.

All subjects mentioned the unsatisfactory performance of the unweighted limb; they had to “wait” for the limb to swing-through, which slowed walking speed. Swing-time decreased as the weight was moved proximally on the prosthetic shank. With 3.97 kg added, inadequate damping moment at full extension resulted in a pronounced jerk. Subjects were most pleased with the behavior of the

prosthesis when weight was placed mid-shank, corresponding to the most energy-efficient configurations identified.

**Future Plans/Implications**—The lightest weight AK prosthesis that can currently be produced is not of optimal mass for efficiency in gait, nor is its functioning acceptable to the AK population of this study. Future work should investigate the effect of varying the knee mechanism to improve performance, and will involve a larger, more diverse amputee population.

#### **Publications Resulting from This Research**

None reported.

### **[33] Geriatric Prosthetics: Design and Development of an Improved Above-Knee Socket**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A308-2RA)*

**Purpose**—The way the forces and moments at a socket/stump interface are transferred to and from a lower limb amputee’s stump and his/her prosthesis is a function of the design of the prosthetic socket, the alignment of the prosthesis, and the biomechanical characteristics of the amputee’s tissues. The way these prosthetic stresses are distributed in the amputee’s stump tissues, in turn, directly affects tissue circulation and metabolism, and amputee comfort and function. Geriatric amputees’ tissue viscoelasticity, circulation, and other physiological and biomechanical properties, in general, differ significantly from those of other, younger amputees. Since the way prosthetic forces and moments are transferred to and from, and are distributed in, a lower limb amputee’s tissues, is a function of the design of the prosthetic socket. It follows that different considerations should be used in the design of prosthetic sockets for geriatric amputees than those used for younger, more active, amputees. The objective of this project is to investigate the prosthetics requirements of geriatric above-knee (AK) amputees, and to develop quantitative

design procedures for prosthetic sockets for these amputees.

**Progress**—Work has continued on measuring the physiological, biomechanical, and prosthetics parameters of geriatric and non-geriatric AK amputees and control subjects. Eighty-nine subjects (51 amputees and 38 control subjects) have been tested to date. The physiological, biomechanical, and prosthetics measurements from these subjects have been compiled in a computer database management system. The data to date evidence a number of statistical trends.

All of the geriatric subjects tested to date, both amputees and non-amputee control subjects alike, have evidenced some degree of circulatory impairment. No common localized regions evidencing either poor or normal circulation have been observed, however, in the geriatric amputees tested. Measurements have shown thigh tissue mechanical elasticity to be anisotropic for all subjects tested. In general, tissue elasticity has been lower (less elastic) on the stumps of the amputee test subjects than on



the thighs of the non-amputee control subjects. The stump tissue elasticities measured on geriatric amputees have been lower, in general, than the corresponding stump tissue elasticities measured on non-geriatric amputees. In addition, no common local regions or common directions exhibiting higher or lower elasticity have been observed on the subjects tested to date. With respect to sensory input and proprioception, twelve geriatric amputees that have been tested evidenced slight sensory diminution in their stumps. But no major impairment has been observed in these or any of the other amputee subjects tested, including those subjects amputated because of peripheral vascular disease. Three of the geriatric amputees showed more localized stump tissue sensory diminution than any of the other amputees tested, but their sensory diminution was localized, and not of major consequence.

Work has continued on AK socket design in conjunction with the above physiological and biomechanical testing. Investigations using tissue compliance measurements with uniform cross-sectional loading for quantitative derivation of socket shape, as previously described, have continued. Compilation of data on prosthetic loading, load distribution, and load tolerance ranges as a function

of stump tissue compliance has continued. Sockets for four more subjects were fabricated and incorporated in prostheses for clinical evaluation and testing, using the uniform force/tissue displacement (UF/TD) socket design method developed under the project and described in previous progress reports.

Work on development of instrumentation for measurement of static and dynamic normal and shear stresses at the stump/socket interface has also continued. Work has proceeded on design and development of miniature shear stress transducers for complete characterization of total socket/stump loading. Several prototypes have been fabricated and are being tested. Testing and calibration of Interlink force-sensitive resistor arrays for measurement of normal stresses at the socket/stump interface has also continued.

**Future Plans**—It is planned to instrument UF/TD and quadrilateral sockets of several test subjects when transducer development is complete.

#### **Publications Resulting from This Research**

None reported.

### **[34] Anatomy and Above-Knee Socket Design**

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**Sponsor:** *Commonwealth Department of Veterans' Affairs, Australia*

**Purpose**—The objective of this research was to devise an above-knee (AK) socket, giving maximum control of the residual limb, without using ischial containment for medio-lateral (ML) stability. The AK socket is based on the actual anatomy of the area.

**Methodology**—Casting is done with an IPOS brim. The femoral residual limb (including the greater trochanter), is marked with indelible pencil on the stockinette, as are the hamstrings and the adductor longus. The plaster cast is then modified to accommodate these vertical prominences.

**Progress**—Five patients were fitted with this “anatomically contoured” socket during 1988-89. The sockets, flexible surlyn liners in either laminated resin or polypropylene frames, were mounted on a modular system.

**Preliminary Results**—One prosthesis broke down and was replaced by a conventional socket. One other patient found the socket comfortable, but did not like the increased rotation of the prosthesis resulting in a heel “whip.” The last three patients, all young and active, have not required any modification of the socket since fitting. They have been



wearing the new anatomically contoured sockets for 4, 10, and 15 months, respectively.

**Future Plans**—Five additional patients will be fitted with this new type of socket. All patients will be analyzed radiologically to monitor possible differ-

ences in the movements of the femoral residual limb in relation to both quadrilateral and contoured sockets.

#### **Publications Resulting from This Research**

None reported.

## **C. Lower Limb**

### **3. Below-Knee**

#### **[35] CAD/CAM of Below-Knee Prosthetics: Program Studies**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A317-2RA)*

**Purpose**—The first project evaluates whether finite-element analysis can accurately predict pressures between an amputee's residual limb and prosthetic socket by comparing experimentally measured pressures with pressures predicted by a finite-element model. A viable model would provide a strong clinical research and design tool; it would aid in quantifying the nature of a good prosthetic fit and provide the prosthetist with a quantitative and repeatable means for socket design.

The second project evaluates spatial foot positioning (alignment) for below-knee (BK) prostheses within a coordinate reference frame established from skeletal geometry. Documentation of positioning variation is made using perturbation methods, with results interpreted for commonalities across individuals suggestive of position prescription derived from anatomical criteria. Future integration of these projects will address coupled effects of socket pressure and foot position.

#### **Computerized Analysis of Below-Knee Amputee Socket Limb Mechanics**

**Progress**—Previous results of linear small-strain finite-element modeling correctly predicted the range of experimental pressure measurements without exact numerical correspondence. Several variations in finite-element formulation have been implemented on existing models of amputee residual limbs. Variations included: changing internal constraints of the bony structures; a non-linear foundation to represent the soft liner of the socket; non-linear material and geometric approaches for tissue; and, incompressible element formulations. Not all approaches increased the accuracy of the surface

pressure predictions. To date, no conclusive, measurable improvement in accuracy was provided by the non-linear modeling of limb tissues. However, the use of constant dilatation elements to model incompressibility in a linear analysis, along with iterative removal of constraints on surface elements which experience tension, has provided a marked improvement in results.

A generic model, created from anthropometric data of the BK limb, is used to investigate the relative effect of modeling variations. Socket-liner stiffness, tissue stiffness, socket taper, and stump

length have all been examined, as has the effect of a typical socket rectification. A fair amount of pre-loading occurred simply by donning the rectified socket. This indicates that results from a modeled limb created using an already rectified shape differ from the results of a model of the same undistorted limb which is both loaded and, by application of nodal displacements, rectified during the analysis.

**Results/Implications**—A barograph device that can be used in conjunction with an MTS testing machine

was built for quantification of *in vitro* tissue properties. Calibration experiments on elastomeric materials were performed and compared to finite-element models. Results are quite good in that displacement and pressure results from the models closely match the experiments. The device will be used in a similar fashion to examine soft-tissue mechanics. It is expected to yield detailed information regarding finite-element modeling of tissue.

### Anatomically-Based A Priori Alignment Prescription Studies

**Progress**—Numerical routines for location of coordinate axes in the hip and knee have been developed. Assumptions about the geometry of the articulating surfaces are used with joint kinematics to obtain location of the origin and the direction of one of the principal coordinate axis. The spatial relationship between hip and knee origins is used to get the remaining coordinate directions. These methods do not rely on palpation or similar estimation of bony features, so coordinate location is reproducible. Using common skeletal characteristics to derive coordinate locations gives correspondence between individuals.

We have nearly completed construction of a motion analysis laboratory for use in the experimental portion of this study. Force plates and a

metalized walkway are in place. Phasic events of walking are monitored using the metalized surface of the walkway and four contacts adhered to the shoe sole. A new circuit has been designed allowing phasic data to be collected without tethered connection of the subject and without radio telemetry. We are well along in modifying and integrating a dual CODA system for high precision kinematic measurement, which completes the setup.

#### Publications Resulting from This Research

**Finite Element Modeling of the Below-Knee Socket and Limb: Phase II.** Steege JW, Childress DS, *Modeling and Control Issues in Biomechanical Systems Symposium of the ASME Winter Annual Meeting*, BED(11), DSC(12):121-129, Chicago, IL, 1988.

### [36] Further Development of the ISNY Below-Knee Flexible Socket System

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A277-2DA)

**Purpose**—The focus of this project has been on the introduction of efficient and comfortable *suction* suspension into the ISNY Flexible Socket System by means of a rubberized air seal located between the below-knee stump and the socket or socket liner, as well as a distally located one-way air valve. The air seal (for which the term “hypobaric” is used) is designed to function independent of the socket configuration (PTB, SC, SC-SP, etc.).

**Methodology**—As a first step, a rubber model of a typical below-knee stump was prepared to stimulate the shape and consistency of the human residuum. Sockets of sheet polyethylene and porous polyethylene (PELITE) were fabricated and fitted on the model in conjunction with the hypobaric seal and valve. Static tests showed that significant retention due to differential air pressure resulted—the data indicating that 50 pounds of force (much more than



would be imposed by prosthetic use) failed to separate the inserts or liners from the model.

**Progress**—Subsequently, an effort was made to introduce the hypobaric seals into a number of unselected below-knee prostheses. However, little success was achieved because air leaks developed as a result of the preexisting sockets being too large for efficient seal functioning. Since the effectiveness of any seal is directly dependent on the closeness of fit of the prosthetic socket, we began the fabrication of a series of new sockets for 20+ patients utilizing accepted ISNY cast modification procedures. As these fittings progressed, we found it useful to revise the modifications in the direction of even more intimate socket fit. This was accomplished by reducing model circumferences by one fourth or more inches, and mellowing and blending all modifications to eliminate possible air channels.

**Preliminary Results/Implications**—The results were much improved with full or partial success being achieved in about one half of the patients. During this process, findings of interest were: 1) The more aggressive cast modification procedures, particularly in the distal portions of the sockets, were tolerated (to a point) without causing discomfort; 2) Although somewhat greater success was achieved with cylindrical as compared to tapered residua, no clear-cut pattern of patient or prosthetic characteristics delineated successful from unsuccessful fittings; 3) In a number of patients, suction retention remained

satisfactory throughout the day. In others, probably related to volume fluctuation, retention became poorer or was lost as the day wore on. For this group, retention could sometimes be restored by the addition of a fresh or thicker interface; 4) There were several instances of skin discoloration (redness) at the level of the seal immediately after removing the prosthesis. These faded overnight; and, 5) Adequacy of socket retention was related to the characteristics of different materials, PELITE providing less satisfactory results than polyethylene or Surllyn.

In light of these findings, it became clear that further progress depended on the isolation and control of several critical variables. Studies were therefore refocussed on laboratory work utilizing residuum models so that independent manipulation of variables might provide more detailed insights and understandings. Current investigations are therefore concerned with: 1) optimal configuration, and location of the hypobaric seal; 2) possible utilization of two seals (one proximal and one distal) to prevent air leakage due to anteroposterior and mediolateral motion between stump and socket; 3) determination of stump-socket-seal clearances for efficient function; and, 4) new socket materials. These data are now being analyzed with a view towards renewing clinical fittings.

#### **Publications Resulting from This Research**

None to date.

### **[37] Biomechanical Power Analysis of Prosthetic Feet: A Pilot Study**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A992-PA)

**Purpose**—Below-knee amputation is a major source of disability and impaired mobility in the elderly. Because of the increased metabolic demand of walking with a prosthesis, a new class of prosthetic components called “energy-storing feet” has the potential to markedly benefit and improve the rehabilitation of this group of amputees.

The major objective of this study is to establish the utility of energy-storing prosthetic components in the dysvascular below-knee amputee. A quantitative evaluation of the mechanical power characteristics of energy-storing prosthetic feet and the amputee’s muscular adaptation during walking will be used to address the following key hypotheses: 1) a

measurable energy storage and release occurs with the energy-storing prosthetic feet which exceeds that of conventional non-energy storing feet; and, 2) energy-storing prosthetic feet will favorably influence the muscular demands and adaptations placed on the residual lower extremity of the amputee.

**Implications**—The data obtained from this study may be expected to serve as a basis for: 1) improved understanding of the gait abnormalities and the role

of energy-storing prosthetic feet in the elderly amputee; and 2) improved gait training programs and prescription guidelines. A major long-term objective of this research is to develop an analytical and conceptual framework for the evaluation of prosthetic components used for all levels of amputation.

#### **Publications Resulting from This Research**

None reported.

### **[38] Dynamic Elastic Response Feet: A Pilot Study**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A517-RA)

**Purpose**—Recent advances in prosthetic design have resulted in the development of dynamic elastic response (DER) feet. Developers claim that these feet store energy during stance and release the energy as body weight progresses forward, thus helping to passively propel the limb. There is little data available to indicate improved ambulation while using DER prosthetic feet. The purpose of this pilot study was to investigate some of the new prosthetic feet, compare them with the SACH foot, and determine if any DER feet demonstrated trends toward producing the most optimum gait.

**Methodology**—We investigated the gait of five below-knee amputees while they were wearing four different DER feet (Flex-Foot, Carbon Copy II, Seattle, Sten) and a standard SACH foot. Each subject used each foot for one month prior to gait analysis at the Pathokinesiology Laboratory. Testing included stride analysis, motion analysis, joint torques, and intramuscular electromyography during free and fast walking. Energy expenditure was tested during a 20-minute free-paced walk.

**Results**—Minimal differences in either free or fast walking were noted between the five feet. The Flex-Foot resulted in a more rapid forward progression of body weight over the foot during single-limb

support when compared to the other four feet. The Flex-Foot also had significantly greater dorsiflexion motion and torque at the end of stance. No differences in energy expenditure were detected.

We expected the DER feet to result in different gait characteristics from the SACH. However, only the Flex-Foot stood apart from the other feet tested. This is not surprising, because the Flex-Foot has a flexible graphite composite keel that extends to the prosthetic socket, whereas the other feet were attached to a rigid pylon. Although the Flex-Foot produced slight changes in gait dynamics, this foot did not produce an increased velocity, nor an improved energy expenditure during free walking.

The results of this pilot study indicated that during free or fast-paced walking on level ground there were no clinically significant advantages of any one of the feet tested. Perhaps level walking did not stress the amputees' gait adequately to elicit the true advantages of these DER prosthetic feet.

**Future Plans**—Further investigation is currently underway to study the response of these feet on ramps and stairs.

#### **Publications Resulting from This Research**

None reported.



### [39] Investigation of the Optimal Load-Bearing Characteristics of Patellar Tendon Bearing (PTB) Prostheses

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Sponsor: National Science Foundation

**Purpose**—The long-term goal of the research team is to automate the construction of lower limb prostheses using computer integrated manufacturing (CIM) techniques. This ongoing project is specifically investigating the load transmission through the stump-socket interface. This information will be combined with the results of two other investigations; one looking at the dynamic and structural characteristics of the prosthesis as a whole, and the other looking at the amputee and his/her compensatory activities due to psychological attitudes or physiological limitations.

The ultimate objective of this project is to lead to an improvement in the quality of prosthetic care delivery, based on quantitative and objective measures.

**Methodology/Progress**—Instrumented prostheses are manufactured for each subject. Interfacial forces are measured at the patellar tendon, as well as pressures at the distal end of the stump. The socket geometry is altered in the patellar tendon and the stump-end regions. These forces and pressures are collected simultaneously with ground reaction forces and kinematic data. The project was broadened to include additional interfacial measurements of forces acting at the tibial crests and the tibial flares. This expansion will be administered with two experimental systems on two amputees. The systems are currently being installed on one prosthesis of a new subject, and a second subject has been selected. Subsequently, the project will be terminated and final conclusions will be drawn.

**Results**—The following is a summary of results for the past year in this ongoing study: 1) the original design of the instrumented prosthesis has been modified extensively to decrease weight and improve and accuracy; 2) the measuring systems have been revised considerably for the purpose of expanding their measuring capabilities as stated above; 3) a mathematical model of the stump-socket interface is being developed; 4) preliminary results have led to an investigation of the accuracy of the gait studies performed, and to conclusion as to the cause of instability at the stump-socket interface, and its probable causes. This information was presented at the 1988 East Coast Clinical Gait Analysis Conference; and, 5) other experimental results have been analyzed and reported in the relevant literature.

#### Publications Resulting from This Research

**Structural Synthesis of Lower Limb Prostheses for Optimal Gait Performance.** Seliktar R, in *Proceedings of the 13th Northeast Bioengineering Conference*, Philadelphia, PA, 1987.

**Toward Automation of the Manufacturing of Lower Limb Prostheses.** Seliktar R, in *Proceedings of the Special Congress of the International Society for Prosthetics and Orthotics*, Israel, 1987.

**Gait Performance Following Skeletal Modification or Lower Limb Amputation.** Seliktar R, Mizrahi J, Vachranukunkiet T, Besser M, Kuenzig D, *IEEE Engineering in Medicine and Biology Society 10th Annual Conference*, New Orleans, LA, 1988.

**Human Performance with Prosthetic Devices and Surgically Modified Skeletal Elements.** Seliktar R, Mizrahi J, Vachranukunkiet T, Besser M, Kuenzig D, Invited Paper, *Automedica*, 11:145-162, 1989.

## **[40] Long-Term Effect of Below-Knee Amputation on Unilateral and Contralateral Knee Function**

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*Sponsor: The Royal Ottawa Health Care Group, The Royal Ottawa Hospital*

**Purpose**—The objective of the study will be to determine the long-term effect of a below-knee amputation on both the amputated side, as well as on the contralateral side, particularly as it involves the knee joint. The premise is that a below-knee amputation produces excessive stress on both knee joints, resulting in premature development of processes such as osteoarthritis.

**Methodology**—The project will entail the physical examination and X-ray of the knee joints of

unilateral below-knee amputees and corresponding documentation.

**Progress**—A literature search has been undertaken and the details of the research proposal are in preparation.

### **Publications Resulting from This Research**

None reported.

## **[41] Optimization of Below-Knee Prostheses Alignment by Postural Sway Parameters**

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*Sponsor: The Technion VPR Fund; J. Tal Equipment and Research Fund*

**Purpose**—In a previous study, we identified parameters for the characterization of postural sway dynamics, which included vector sequence of the bilateral reactive forces acting on both feet while a subject is standing still, during sway activity, and with feet in an asymmetrical stance. We developed and implemented a method to study various population groups, including normals, cerebrovascular accident (CVA) patients, and chronic coronary insufficiency (CCI) patients. In this study, the method is being adapted for below-knee amputees, fitted with prostheses, for the optimization of the alignment of their prostheses. The standard procedures of prostheses alignment have so far involved numerous gait tests, requiring a considerable amount of physical effort and cooperation from the amputee. The proposed standing sway test also allows us to perform an alignment procedure on amputees who are unable to do the exhaustive gait tests (e.g., elderly amputees, and those with amputations due to vascular problems).

**Methodology**—Postural sway is measured by two Kistler force platforms (Type Z 4305), collaterally installed for adjacent positioning of the left and right feet during standing. The foot-ground reaction forces in the vertical, anteroposterior and mediolateral directions are simultaneously monitored for both feet during the swaying tests. The force signals from the Kistler amplifiers are sampled by an IBM-XT computer. The following parameters are determined and/or analyzed: 1) waveform recognition; 2) relative sequence of the force vectors on both feet; 3) timing and amplitudes of waveforms; and, 4) force activity, including weight-bearing imbalance, sway total activity, and asymmetry.

**Results**—Eleven amputees have participated in this study so far. The standard sway test included four runs: two with the eyes open, and two with the eyes closed, in order to study the effect of visual feedback on postural sway. The results obtained were evaluated in two ways: 1) comparison of the



sway characteristics obtained with those of normal population; and, 2) comparison between the amputated side (with prosthesis) and contralateral (normal) side.

Additionally, the above procedure was repeated during a follow-up period to test the effect of adaptability to the prosthesis on the results obtained.

Significant differences are seen between the results for amputees and those of the normal population. More important are the differences found between the prosthetic leg and the sound leg.

**Future Plans/Implications**—An attempt will be made to correlate the differences found to the

specific pathology of each amputee. The next stage will be to study the effect of deliberate variations in alignment on the results obtained, in order to optimize the prosthesis alignment.

#### **Publications Resulting from This Research**

**Postural Stability in Stroke Patients: Vectorial Expression of Asymmetry, Sway-Activity and Relative Sequence of Reactive Forces.** Mizrahi J, Solzi P, Ring H, Nisell R, *Med Biol Eng Comput* 27:181-190, 1989.

**Bilateral Reactive Force Patterns in Postural Sway Activity of Normal Subjects.** Mizrahi J, Susak Z, *Biol Cybern* 60(4):297-306, 1989.

**Standing Posture of Craniocerebral-Injured Patients: Bilateral Reactive Force Patterns.** Mizrahi J, Groswasser Z, Susak Z, Reider-Groswasser I, *Clin Phys Physiol Meas* 10:25-37, 1989.

## **[42] Gait of Children Having a Unilateral Below-Knee Amputation**

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**Sponsor:** *Variety Club of Southern Alberta—Tent 61 through Alberta Children's Hospital*

**Purpose**—The long-term objective of our research is to enable below-knee amputee (BKA) children to stand, walk, and run similarly to normal children without adversely affecting their comfort and skeletal health. To attain this objective, it is necessary to develop a comprehensive research program that: 1) describes the gait characteristics of BKA children and compares these characteristics with normal children; 2) determines the etiologies and underlying mechanisms explaining any differences between these gaits; 3) determines potentially detrimental effects of existing differences; and, 4) explores the possibility of allowing the BKA child to obtain gait characteristics similar to those of normal children through prosthetic design, rehabilitation, and medical intervention.

**Progress**—We have performed a series of studies aimed at describing the standing, walking, and running characteristics of BKA and normal children. These studies are a first step in a longitudinal investigation in which we will monitor the gait characteristics of BKA and normal children every six months for five years.

**Results**—We have found that BKA children stand, walk, and run differently than normal children in terms of both kinematics and kinetics. With respect to kinetics, we found that external forces of the nonprosthetic limb during walking were significantly greater than those of the prosthetic limb, and greater than those of the limbs of normal children. Based on these results, we speculate that BKA children may be at greater risk for future degenerative joint disease of the nonprosthetic limb than normal children. This speculation is supported by findings from Hungerford and Cockin (1974), and Burke *et al.* (1978), who reported a higher incidence of degenerative joint disease in adult lower limb amputees than the normal population, and by those of Radin and Paul (1971), who reported that higher than normal impulsive loading was correlated with degenerative joint disease.

With respect to kinematics, we found that for running, the BKAs exhibited a substantial amount of frontal plane rotation of the prosthetic leg during support. We also found that the normal children exhibited very little of this leg rotation. From these results, we wanted to state that frontal-plane-leg

rotation for the BKAs could measure the amount of knee instability for these children. We could thus quantify the knee instability possessed by the congenital amputees with deficient knee-joint structure. However, one of the amputee children who exhibited the same leg rotation as the others, lost his limb as a result of trauma, and thus had normal knee joint structure. We therefore had to consider other possible reasons for this leg rotation. We speculated that one possible reason was that the children did not have a talocalcaneal joint as a part of their prosthesis. We developed a model to investigate that possibility.

This model, along with additional kinematic data, led us to believe that while the lack of a talocalcaneal joint could contribute to some leg rotation, it could not account for all of it. Other possible contributions could arise from the residual limb-socket interface or the socket-prosthesis interface. A generalized model which could consider multiple segmentation of the leg and foot appears warranted.

**Implications/Future Plans**—The number of children in our longitudinal investigation is small (4 BKAs and 11 normals). It is therefore important to establish that these children comprise a representative sample from their respective population. In this regard we have collected standing, walking, and running data for 237 normal children, ages 7 to 12

years. We will be collecting this same data on 30 BKA children. With the reporting of this information, we will have established normative descriptive data for both normal and BKA children.

### Publications Resulting from This Research

**Changes in Gait Kinematics for Recent Below-Knee Amputee Child.** Engsberg JR, Tedford KG, Harder JA, Mills JP, in *Proceedings of the IEEE Engineering in Medicine & Biology*, (2):0616, 1988.

**Knee Instability in Fibular Hemimelic Below the Knee Amputee Children.** Engsberg JR, Harder JA, Allinger TL, Clynch G, *J Biomech* 21(10):883, 1988.

**Biomechanical Analyses of Children with a Below the Knee Amputation: Longitudinal Approach.** Engsberg JR, Harder JA, Tedford KG, in *Proceedings of the Association of Children's Prosthetic-Orthotic Clinics Annual Meeting*, Chicago, IL, 1989.

**Force Platform Analysis of Gait of Children with Below-Knee Amputation: Horizontal Components.** Lee AG, Engsberg JR, Harder JA, in *Proceedings of the ASME Winter Meeting*, 1989.

**Force Platform Analysis of Gait of Children with Below-Knee Amputation: Vertical Components.** Patterson JL, Engsberg JR, Harder JA, in *Proceedings of the American Society of Biomechanics*, 110-111, 1989.

**A Function of the Talocalcaneal Joint During Running Support.** Engsberg JR, Allinger TL, in *Proceedings of the American Society of Biomechanics*, 128-129, 1989.

**Kinematics of Below-Knee Amputee Children During Running.** Engsberg JR, Aldridge KC, Harder JA, in *Proceedings of the International Olympic Committee First World Congress*, Colorado Springs, CO, 1989.

**Standing Pressure Distribution for Normal and Below the Knee Amputee Children.** Engsberg JR, Allinger TL, Harder JA, Clynch G, *Prosthet Orthot Int* (accepted for publication).



## II. Orthotics

*For additional information on topics related to this category see the following Progress Reports: [5], [6], [7], [231], [289], [302], [318], [392].*

### [43] San Francisco Molded Shoe Therapeutic Evaluation and Risk Stratification

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A010-3DA)

**Purpose**—The purpose of the Therapeutic Molded Shoe phase of the project was to design a system to fabricate a molded shoe that would fulfill the following requirements: improved therapeutic effectiveness, reduced costs, shortened turnaround time, and improved cosmesis.

**Progress**—The shoe is designed for diabetic patients with insensate feet who have a history of plantar foot ulceration but who have not yet undergone major foot amputations or developed marked foot deformities. Fifty patients have been fitted with custom footwear using new technology developed during the course of the project. The patients have been followed and evaluated subjectively and objectively with respect to the effectiveness of the system in healing plantar ulcerations. Four patients who had ulcerations in the past continue to be treated for recurrent ulceration at previous ulcer sites. Two patients have developed ulcers secondary to shoe irritation. Following shoe modifications, these lesions resolved and the patients are doing well. Evaluation forms sent to patients are currently being reviewed. A final comprehensive report of our experiences and results is being written.

**Preliminary Results**—The risk stratification aspect of our project defines the prevalence of foot pathology, lower extremity complications, and

known risk factors for ulceration in a cross-sectional analysis of 92 diabetic patients from our metabolic clinic. This phase of our project is complete. The results have been published.

**Future Plans**—A Request For Evaluation (RFE) of all the components of the San Francisco VA molded shoe system has been submitted. Five test sites for the system need to be selected. Each test site will use and evaluate the system on 40 patients. Results will be reviewed to determine if the system can be adopted nationwide.

A request for a brief extension of the project has been submitted to determine if the shoe can be used with patients having significant foot deformity and/or amputation.

#### **Publications Resulting from This Research**

**High Resolution Ultrasound in the Preoperative and Postoperative Assessment of Distal Metatarsal Osteotomy.** Graf PM, Farac K, Stess RM, Gooding GAW, *Invest Radiol* 23(11), 1988.

**Aesthesiometry: Quantification of Cutaneous Pressure Sensation in Diabetic Peripheral Neuropathy.** Holewski JJ, Stess RM, Graf PM, Grunfeld C, *J Rehabil Res Dev* 25(2):1-10, 1988.

**Prevalence of Foot Pathology and Lower Extremity Complications in a Diabetic Outpatient Clinic.** Howleski JJ, Moss KM, Stess RM, Graf PM, Grunfeld C, *J Rehabil Res Dev* 26(3):35-44, 1989.

## [44] Functional Tasks Restored in Paralyzed Man Using Electronic Orthotics

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B193-4RS)

**Purpose**—The long-term objectives of this study are: 1) to design and implement a functional neuromuscular stimulation (FNS) system which will allow paralyzed individuals to use crutches for walking on levels and ramps and for climbing and descending stairs; and, 2) to provide it in an implantable form. During the past year we have emphasized development of external stimulator/controller hardware, stimulation software and muscle implantation methods.

**Preliminary Results**—*Muscle Electrode System.* A new prolene-core electrode design was developed with a double helix of stainless steel multistrand wire to serve as a tension release, and the implantation technique was revised to remove stresses. Currently, the cumulative proportion of electrodes which survive at the end of one year is 78 percent, as compared to earlier versions with 40 percent or less surviving. A new design for a percutaneous/epimysial electrode has been developed to serve as a transition from the percutaneous to the implanted FNS systems.

**Hardware.** We have developed both laboratory-based and portable 48-channel stimulators. The laboratory system can be used for either preprogrammed or closed-loop stimulation which is based on sensor information. Interactive graphics software was developed for the setting up and modification of open-loop stimulation patterns by therapists. The stimulator contains safety circuitry which warns the user of a broken electrode and of low power. Compliance monitors keep records of stimulation time of functional activities. The user selects a function with a joystick on a finger-mounted control ring. The portable stimulators are capable of controlling the Case Western Reserve University (CWRU) 8-channel implantable stimulator.

We acquired and are adapting a four-camera video-based motion data collection/analysis system.

**Control of Stimulation.** We have developed

feedback stimulation control software on the MicroVAX system for in-lab system development and experimentation/data analysis. The software allows the integration of feedback-controlled stimulation of certain muscles within (and replacing parts of) the open-loop stimulation patterns.

We have adapted commercially available sensors for use in closed-loop control. Signal processing algorithms have been used for detection of falling, center of foot pressure, knee moment, and hip/trunk angle.

A 2-D double-stance biomechanical simulation of gait has been developed, including a two-segment trunk model. The model was expanded to include special constraints at the joints, such as braces or passive moments.

We have developed closed-loop control algorithms for the control of single joints, which can also be used in concert. In standing, the results indicate that we can adjust the effective stiffness of the joints to desired levels. A real-time identification algorithm has been developed, which detects changes in muscle input/output properties, a necessary characteristic for an adaptive controller which can compensate for fatigue.

A discrete event model of paraplegic gait was developed to provide a framework for the controller operation. Its validation is underway. In an effort to optimize stimulation for fatigue resistance we are evaluating an algorithm which uses both pulse width and stimulus period modulation.

**Enhancement of Ambulatory Function.** Walking speeds at 0.4-0.7 m/s have been achieved with distances of up to half a mile. We have achieved some crude open-loop crutch walking with assistance. One paraplegic subject used the FNS system functionally to get onto rides in Disneyland, using one crutch and one assistant for support.

**Future Plans/Implications**—The main effort in the next year will be to combine the various open- and closed-loop stimulation techniques. We are develop-



ing a lower-body harness to provide sensor mounting sites and regulation of certain motions. We believe that this device, together with existing sensors and control algorithms under development, will allow independent crutch-walking for the paraplegic.

#### **Publications Resulting from This Research**

**Development of a Practical Electrical Stimulation System for Restoring Gait in the Paralyzed Patient.** Marsolais EB, Kobetic R, *Clin Orthop* 233:64-74, 1988.

**Control of Functional Neuromuscular Stimulation Systems for Standing and Locomotion in Paraplegics.** Chizeck HJ, Kobetic R, Marsolais EB, Abbas JJ, Donner IH, Simon E, in *Proceedings of the IEEE*, 76(9):1155-1165, 1988.

**Simulation of the Double-Limb Support Phase of Human Gait.** Ju M-S, Mansour JM, *J Biomech Eng* 110:223-229, 1988.

**Development and Operation of Portable and Laboratory Electrical Stimulation Systems for Walking in Paraplegic Subjects.** Borges G, Ferguson K, Kobetic R, *IEEE Trans Biomed Eng* 36(7):798-801, 1989.

**Tetanic Responses of Electrically Stimulated Paralyzed Muscle at Varying Interpulse Intervals.** Carroll SG, Triolo RJ, Chizeck HJ, Kobetic R, Marsolais EB, *IEEE Trans Biomed Eng* 36(7):644-653, 1989.

### **[45] Development of a Powered Orthosis for Lower Limbs**

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**Sponsor:** *Institute of Physical and Chemical Research, Agency of Science and Technology, Japanese Government*

**Purpose**—In order to restore an appropriate gait pattern, a powered orthosis is being developed for paralyzed lower limbs that will support the patient's body and control lower limb movement. As a final goal, the powered orthosis will enable paraplegic patients to walk on level ground with a variable cadence, to stand and sit, and to go up and down a staircase by appropriate command.

**Progress**—Considering the results obtained experimentally through preceding years, a second prototype was designed and constructed in 1986. Its main purpose was to have a powered orthosis for lower limbs of an appropriate size, so that control methods explored in the past several years could be tested on paraplegic patients. The orthosis was fabricated in carbon-fiber reinforced plastic (C-FRP), and in the thigh and femur parts, four electrohydraulic actuators were incorporated. These actuators now have digital controls, in contrast with the first prototype which used an analog type. Each actuator is controlled by a single-board microprocessor, and all of these are totally controlled by a host microcomputer. Sensory systems such as foot-switch sensors to detect plantar contact, optical encoder to measure relative joint angle, and posture sensor to measure torso inclination in sagittal and frontal planes are used to accomplish a stable powered walk. The orthosis itself weighs 19.5 kg, and its

control wagon 68 kg, which should be moved with the powered walk. A powered orthosis will be realized using these two components.

**Preliminary Results**—After having checked the basic function of the powered orthosis on a normal subject, it was tested on two paraplegics: both patients could walk with this powered orthosis, grasping the rail of the wagon for balance. This second version of the powered orthosis has sufficient torque for powered walk. After some modifications of the software program, one of the patients realized a powered walk at a cadence of 4.5 second/step, while the former cadence was 6.0 second/step.

**Future Plans**—Since the first tests on paraplegics have been successful, the control methods developed on the first prototype will be applied to the second prototype to improve the function of the orthosis. As two orthoses have been constructed which are identical except for geometrical size, all the control methods will be thoroughly tested on normal subjects prior to the clinical tests.

#### **Publications Resulting from This Research**

**Developpement d'une Orthese Active des Membres Inferieurs.** Miyamoto H, Numao T, Ueda K, Sano A, Mori, S, Sakurai Y, in *Proceedings, ICAART 88*, Montreal, 92-93, 1988.



**Powered Orthosis for Lower Limbs.** Miyamoto H, Ueda K, Sano A, Mori S, Nakajima I, Akamatsu N, Sakurai Y, in *Proceedings of the 11th Biomechanical Symposium (SOBIM Japan)*, 221-230, 1989 (in Japanese).

**Powered Orthosis for Lower Limbs.** Miyamoto H, Sakurai Y, Nakajima I, Akamatsu N, in *Proceedings of the 3rd French-Japanese Biomedical Technologies Symposium*, 1989 (in press).

## **[46] A Practical, FES-Powered Walking Orthosis for Thoracic Paraplegia: The RGO II**

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**Sponsor:** National Science Foundation; Louisiana Board of Regents

**Purpose**—A mechanical orthosis consisting of thoracic, hip, knee, ankle, and foot support was developed and tested on over 750 patients. The device, called the Reciprocating Gait Orthosis II (RGO II) allows thoracic paraplegics a hands-free standing balance and stability, and a reciprocal walking mode when used with a rolling walker or crutches. To reduce the energy consumption required during ambulation, electrical stimulation of the thigh muscles was added. The stimulation system consists of a 4-channel, battery-powered portable system which provides hip flexion simultaneously with hip extension to produce the swing phase of one leg with contralateral push-off. An additional function is to allow a functional electrical stimulation (FES) assist for standing up and sitting. All functions are controlled with thumb switches mounted on the handlebars of a walker.

**Progress**—Recent developments include the design of a flexible thigh cuff incorporating all electrodes and leads, to allow easy and quick application by the patients. Only two thin cables with one-way

connectors plugged into the stimulator. The hip joint was also modified to allow 20 degrees hip flexion for purposes of safe and stable walking up a ramp. The knee joints were replaced with a newly-developed ratchet mechanism which provides the patient with a safe standing-up function, even in the presence of the hamstring's contracture, which is common to paraplegics.

**Results**—Energy consumption studies show that the FES-powered RGO II requires 15 percent less energy than the former RGO, while providing upper and lower limb work-up to reduce overall stress. Stress reduction was manifested by heart rate of 12 beats/min less than the former RGO.

The RGO II and the stimulation system are now manufactured by commercial firms.

### **Publications Resulting from This Research**

**The RGO Generation II: A Practical Walking Orthosis for Thoracic Paraplegics.** Solomonow M, Baratta R, Hirokawa S, Beaudette P, Rightor N, Walker W, Shoji H, D'Ambrosia R, *Orthopedics* 12, Oct. 1989.

## **[47] Further Development of a Protective Helmet for Disabled Persons**

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**Sponsor:** National Health Research and Development Programme

**Purpose**—The purpose of this project is to develop prefabricated protective headwear that would provide effective head and facial protection for children

who frequently fall. Specific goals are to: 1) develop a second-generation helmet that provides appropriate anatomical protection, is custom-fitted, comfort-



able to wear, looks attractive, and is reasonably priced; 2) evaluate the biomechanical performance of the helmet in the laboratory; and, 3) assess the subjective acceptance and performance of the helmet through clinical trials.

**Progress**—Based on the results of the performance of the helmet developed as part of an earlier research project, creation of the second-generation prototype has focused on the enhancement of its impact properties and structural integrity. Improvements in liner fit, ventilation, and hygiene are also intended without compromising the helmet's general cosmesis. A review of anthropometric data on head sizes of children aged 5 through 19 years has enabled the project team to establish the goal of developing protective headwear for nominal head circumferences of 490 mm to 580 mm. As a result, two helmet sizes are being developed to fit children with head circumferences in this range. Alternatives to full-contact cranial and facial protection were investigated in an effort to enhance ventilation and minimize the complexity of the helmet's construction.

Alternative shell and liner materials and the means for fabricating them were also investigated.

The Rehabilitation Engineering Department's newly acquired computer-aided drafting workstation utilizing AUTOCAD software was used extensively in establishing a headform database. Three-dimensional computer models have been used to create and verify modified helmet configurations. A digitized model, providing accurate mapping for the creation of molding casts, has been produced for the pre-assessment prototypes. The first prototype created consists of a thermoformed Kydex shell and a medium density polyethylene foam liner.

**Future Plans**—The shell liner configuration will be confirmed through trials on young children with head circumferences in the 490 mm to 540 mm range. Following this, modifications will be made and the pre-production helmet will be produced and evaluated for its biomechanical impact properties at Cooper Canada test facilities. Subjective evaluations will follow with the assistance of ten children who will each be fitted with a helmet and will wear it for a number of months.

#### **Publications Resulting from This Research**

None reported.

## **[48] Functional Biomechanical Characterization and Functional Design Specification: Orthotics**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Orthoses are applied at the surfaces of the body and act on the joints through the intervening soft tissue layers. This compliant interface can be expected to compromise the ability of the device to effectively control joint positional relationships. By studying the characteristics of this soft tissue interface between an orthosis and the underlying bones, we will be able to answer some of the questions regarding the functional capability of orthotic devices and provide data that can be used in the educated design of such appliances.

Focusing on knee orthoses, we use a generic interpretation of common cuff styles and examine the degree of laxity present between the cuff and the

underlying bone. The laxity range is evaluated in both a static and dynamic test protocol, each involving the application of loads to the orthotic cuffs, in specified directions, and measuring the resulting displacements of the cuffs relative to the bones. Repeating the protocol using the various cuff styles will elucidate what features provide a satisfactory functional performance.

**Preliminary Results**—A survey of common cuff styles has been made and the general features classified into three categories based on the surface area of contact between the cuff and the limb, as well as the region of action between the cuff and the



limb. Generic cuffs representing each of the three cuff principles will be used in the study.

Small, relatively inexpensive six-degree-of-freedom load cells have been identified for use in experimentation. Displacement measurements will be made with the 3Space Tracker which outputs six components of displacement. We are nearing com-

pletion of evaluation of the 3Space Tracker and it appears that, used in a controlled manner, it will provide sufficient accuracy for the tests.

#### **Publications Resulting from This Research**

None reported.

### **[49] New, Lightweight, Inexpensive, Modular KAFOs for Persons with Paraplegia**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research; The Meadows Foundation*

**Purpose**—Our research is designed to demonstrate the feasibility of a new, innovative approach to the problem of providing orthotic assistance for the patient with paraplegia early in the course of a comprehensive rehabilitation program. Professionals are faced with making judgments about the priority of goals regarding ambulation possibilities for patients with paraplegia. These priorities determine the allocation of resources to assist the patient in accomplishing those goals. The use of multi-adjustable knee-ankle-foot orthoses (KAFOs) (clunkers) does not provide the necessary clues because of the complexity and inadequacy of the adjustments necessary. Thus, important information needed to judge the appropriateness of providing the individual paraplegic patient with bilateral custom-fitted Craig-Scott-type leg braces is most often lacking. Consequently, the decision is usually made to prescribe custom metal orthoses to provide the patient with a valid opportunity to experience “what it will be like” to use braces and crutches as a primary means of mobility. The wisdom of that judgment can be seriously questioned when learning that many patients discard their expensive conventional orthoses as being impractical shortly after being discharged from the rehabilitation program.

**Progress**—We have designed, fabricated and pilot-tested an inexpensive, lightweight, modular KAFO that will assist paraplegic patients in: 1) standing during early stages of their rehabilitation; 2) exercise ambulation for improvement of endurance for physical activities, including swimming pool activities; 3)

gait training; and, 4) ambulation within home or community.

A new approach to orthotic management of paraplegic patients is used in which the modular KAFO is initially supplied (virtually “off-the-shelf”) so that inpatients can participate in a standing program very early in their rehabilitation. The initial standing program and gait training activities of these patients are performed using braces with the knees locked. Therefore, early design considerations have focused on the development of side members which have no knee joint. Modifications and adjustments of the modular components can be made in the clinic to obtain a proper fit in a matter of hours. No shoe attachment is required because the foot-ankle support fits inside the shoes. Our new orthosis is custom-fitted to the user and the end product is substantially lighter, cheaper, and more cosmetically acceptable than conventional metal braces. At the same time, the device is strong enough to meet the ordinary needs of users, providing safe stabilization of the lower extremities.

We have conducted clinical trials with the new orthoses on 25 patients with spinal cord injury. Their diagnostic classification ranged from C6 to L3. Patient acceptance of the device has been excellent. No adverse effect on any participant has been noted. Also, no mechanical failure of the system has been recorded. We have continued to work on the design of a streamlined, modular knee joint and have begun pilot testing several different mechanisms for locking and unlocking the knee joint. Patent application procedures have been



initiated through the Baylor College of Medicine. A training manual on the philosophy and procedures for evaluation, fitting, and training patients in the use of our new orthotic system is being drafted. Our next step is to determine the ease with which staff in another facility can use our training manual, and a supply of basic components to evaluate, measure, fabricate, and fit a patient with our modular orthoses and to assess the patient's and the staff's opinions of the clinical usefulness of the devices.

**Future Plans**—Another important potential outcome of our research project is to make good quality inexpensive, lightweight, custom-fitted standing/walking leg frames/KAFOs available for use in

less-developed countries not having access to conventional orthotic services. We expect our modular components to be supplied at modest expense to nearly any setting. The components will be selected from a limited number of sizes and custom-fitted to the patient in the clinic using simple tools. The fitting procedures are simple enough that a technician with mechanical aptitude can very probably be trained in a matter of a few days to assemble and fit them. Thus, better services can be anticipated to become available to persons with paraplegia in underdeveloped countries—as well as in our own.

#### **Publications Resulting from This Research**

None reported.

### **[50] Prospective Evaluation of Invasive and Non-Invasive Treatment Protocols for Plantar Fasciitis**

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**Sponsor:** *None listed*

**Purpose**—The investigators noted a consistently high number of patients within their outpatient practices who were suffering from disabling plantar fasciitis. They also found that each investigator had been prescribing a totally different but standard invasive or non-invasive treatment for this condition. In light of the high cost of custom orthoses and the morbidity of surgery, the investigators sought to prospectively investigate effective treatment for plantar fasciitis. The purpose of this study is to identify a clinically successful, yet cost-effective, conservative treatment for plantar fasciitis.

**Methodology**—The study consisted of the informed, voluntary entry of 40 male veterans suffering from plantar fasciitis into one of five arms of a treatment protocol assigned on a random basis. The disorder was defined for the study by the classic symptoms of heel and longitudinal arch pain (greatest upon arising in the morning), and localized tenderness of the anteromedial calcaneus. Patients screening positive for calcaneal fracture, acute injury, or diabetes, were excluded from the study. One of five standard non-surgical treatments for plantar fasciitis, with which one or more of the investigators had consider-

able experience, was prescribed on a random, prospective basis: 1) plantar fascia/Achilles tendon stretching with ice to the heel and shin curl exercises alone (n=7); 2) exercise plus a stock anatomic orthotic support [Accomodator, Alimed] (n=13); 3) exercise, orthosis, and lidocaine injection (n=4); 4) exercise, orthosis, lidocaine, and corticosteroid injection (n=9); and, 5) exercise, lidocaine-cortisone injection, but no orthosis (n=7). Use of shoes in good repair was also advised, but no further medical or physical therapies were prescribed. Patients were followed at 1, 3, and 6 months. All had foot X-rays for evaluation of possible heel spur, and an assessment of pain and tenderness on separate 4-point scales. Five had bone scans. If there was no sign of clinical improvement by three months, then an alternative treatment was offered.

**Preliminary Results**—Three treatment protocols met with significant success in relieving plantar fasciitis. They include: use of the orthosis alone, use of lidocaine injection plus orthosis, and use of steroid injection plus orthosis. Patients who were injected and also wore the orthosis were consistently improved on both the pain and tenderness scale by



some 70 to 80 percent by one month, and had no pain at three and six months. Those who wore the orthosis alone (without injection) were at least 50 percent improved by one month, 90 to 95 percent improved by three months, with no patients reporting pain or tenderness at six months. Upon comparison of the clinical result of these three groups, the use of injection showed no significant improvement over the use of the orthosis alone. All seven patients treated only by exercise had no change in symptoms at three months, and were offered alternative treatment. Two of seven patients treated by injection (without orthosis) had continued severe, disabling pain through three months, while another two had moderate pain through six months. There were seven failures of treatment in the group given exercise only, and two failures in the group given steroid injections without use of orthosis. A majority of patients were found to have a calcaneal traction spur on the radiographs, but only 35 percent of those were 3 mm or greater in size, and no relationship between size of the spur and clinical improvement was noted. Three of five bone scans revealed an area of increased uptake in the area of a

calcaneal spur. The study is continuing through a follow-up of 90 patients.

**Results**—The results would indicate that a relatively inexpensive anatomic stock orthosis of the type used in this study provided a marked amount of relief from the disabling symptoms of plantar fasciitis by one month, and nearly complete healing by three months. This positive response to treatment was essentially no different from those patients treated by the additional and invasive use of steroid or lidocaine. All patients who wore an orthosis improved significantly over the baseline comparison group that was prescribed a standard series of exercises commonly recommended for the treatment of plantar fasciitis. The preliminary findings of this ongoing study led us to conclude that the use of the stock anatomic orthosis would be the simplest, most cost-effective, and clinically-effective treatment for the disabling disorder of plantar fasciitis.

#### **Publications Resulting from This Research**

None reported.

## **[51] Shoulder Control of Hand Function**

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**Sponsor:** *Natural Sciences and Engineering Research Council; Canadian Paraplegic Association; Lyndhurst Hospital*

**Purpose**—A functional neuromuscular stimulation (FNS) orthosis developed at Case Western Reserve University, Cleveland, Ohio is being used in this pilot study. The orthosis provides a quadriplegic person with palmar grasp and a lateral or key grip. It is controlled by contralateral shoulder movements and by operation of a chest-mounted switch.

Control strategy for opening and closing the hand is being examined. The original strategy was positional control, where the position of the shoulder corresponds to one particular hand position. We are implementing a velocity-control algorithm in which the rate of hand opening or closing is proportional to the deflection of the shoulder joystick.

Position control is easy to learn: the user feels directly coupled to the device being controlled. In

contrast, velocity control is more difficult to learn. It requires more complex software, signal processing, and calibration, but permits higher resolution of the controlled parameter than position control. Because it is a relative control device, it can incorporate a dead-zone or null region, where the output signal remains constant despite small input variations. Velocity control allows a resting region and in some ways is less physically and mentally demanding than position control.

**Methodology**—Successful implementation of velocity control requires knowledge of the shoulder as an input source. This research seeks to investigate the range of shoulder motion and the discrimination of movement within that range. Some shoulder positions may be more consistently and reliably achieved



than others. This area of work is based on Fitts' law and Poulton's research into step tracking. The importance of feedback has been evident in this study.

A person's ability to resolve shoulder movement increases dramatically when visual quantitative information is provided. Without extrinsic feedback, about five regions may be successfully targeted. With screen-based feedback, the number of discrete levels rises to at least 20.

A number of functional tasks were used to evaluate the effect of modifications to the control system. These were based on the group's previous functional assessments, and on tasks where the participant feels the system provides functional benefit. The tests chosen have well-defined starting and ending points. Although the time required to complete a task is the major performance metric, the quality of grasp and release is apparently equally important. Errors and the amount of shoulder movement are therefore being measured as well.

Screen-based assessments are also being developed to assess shoulder performance in those people without the FNS orthosis.

**Progress**—1) A velocity control algorithm has been developed and is being refined during testing with a quadriplegic subject; 2) a functional testing battery is being extended and modified; and, 3) a series of screen-based tasks are being developed and will be administered to quadriplegic subjects and a control group without spinal cord injuries.

**Implications**—The control system modifications may lead to an improved orthosis. Shoulder control is applicable to other prosthetic devices such as myoelectric hands and elbows. As more is learned about the shoulder as an input source, this knowledge may be used to develop methods that quadriplegics can use to control other devices. It could be especially useful in direct-manipulation computer interfaces and word processing.

#### **Publications Resulting from This Research**

**A Pilot Study in the Implementation of an FNS Orthosis.**  
Limpert B, in *Proceedings of the Canadian Medical and Biological Engineering Conference*, Montreal, 149-150, 1988.

## **[52] Orthokinetic Orthoses: Clinical Efficacy Study of Orthokinetics Treatment for a Patient with Post-Cerebral Vascular Accident Upper Extremity Movement Disorder**

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**Sponsor:** *Orthokinetics Research Foundation*

**Purpose**—This study investigated the efficacy of orthokinetic orthoses application to the hemiparetic left upper extremity of a patient six months post-cerebral vascular accident (CVA), who had no functional use of the upper extremity.

**Progress**—The patient lacked active left elbow extension, which could not be restored by conventional physical and occupational therapy treatments prior to application of orthokinetic orthoses. The treatment of dyskinesia of the affected upper extremity comprised a single-subject time-series pilot study, followed by 35 clinical orthokinetics treatment sessions of one hour each, administered over a total period of 13 weeks, and designed on the basis of the outcome of the pilot study.

**Results**—The patient was a 61-year-old male with left hemiparesis six months post-CVA. An experimental orthokinetics treatment, in single-subject design, was administered to the upper extremity, comprising the time-series A1-C1<sup>1</sup>-A2-C2<sup>1</sup>-A3-B1-A4-B2-A5-B3-A6-C1<sup>2</sup>-A7-C2<sup>2</sup>-A8-B4: A1 to A8 = nontreatment phases; C1<sup>1</sup>, C1<sup>2</sup> = placebo treatment phase; C2<sup>1</sup>, C2<sup>2</sup> = sham treatment phases; B1 to B4 = orthokinetics treatment phases. The application of orthokinetic orthoses was based on the following rationale: the neurophysiological mechanism of orthokinetics treatment for dyskinesia invokes the difference in elasticity between the active and inactive fields of the orthokinetic cuff, overlying muscle agonist(s) and antagonist(s) respectively, with resulting facilitation of the agonist(s) by selective cutane-

ous stimulation of low-threshold, slowly-adapting mechanoreceptors via excitation of  $\alpha$ -motoneurons, and of  $\gamma$ -motoneurons by  $\alpha$ - $\gamma$  coactivation, with reciprocal inhibition of antagonist musculature(s). During orthokinetics treatment, four orthokinetic orthoses (cuffs) were applied, two each on the patient's arm and forearm, positioned for facilitation of elbow extension. The treatments were administered to the patient single-blind. The outcomes were consonant with the described neurophysiological theories of orthokinesis remediation of dyskinesia. Internal validity (cause-effect relationship) was tested by inclusion of the nontreatment control phases, placebo treatment phases, and sham treatment phases, with the orthokinetics treatment phases in the single-subject time-series design. During baseline phases A1 through A3, active range of motion (AROM) of the elbow was 0 degrees (i.e., no remediation). In contrast, in orthokinetics treatment B1, AROM of the elbow increased to 30 degrees, then reversed to 0 degrees in nontreatment phase A4; increased to AROM=35 degrees in orthokinetics treatment replication phase B2; reversed to 0 degrees in nontreatment control phase A5; and rose again to AROM=35 degrees in orthokinetics treatment phase B3; during baseline replication phases A6 through A8, AROM remained at 0 degree

baseline level, then rose again to AROM=35 degrees in orthokinetics treatment replication phase B4. These outcomes were consistent with application of the orthokinetics treatments and hence supported its internal validity. The active elbow range of motion of 35 degrees, achieved during the pilot study, subsequently increased to 125 degrees, with carry-over, in the course of a total of 35 orthokinetics treatments, during 13 weeks, on a home treatment schedule of three sessions per week of one hour each. The outcomes supported clinical efficacy of the orthokinetic orthotics intervention, as well as its internal validity (causality).

**Future Plans**—Future plans for the project include further investigations of internal, external, and clinical validity of orthokinetic orthotics in treatment of persons with stroke, and traumatic brain injury, for dyskinesia and chronic pain. These studies are part of an ongoing cooperative clinical study on the utilization of orthokinetic orthotics in physical and neurological rehabilitation therapy research.

#### **Publications Resulting from This Research**

None reported.

### **[53] Development, Manufacture and Clinical Evaluation of a Modular Wrist, Hand and Finger Orthosis System**

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**Sponsor:** *Scottish Home and Health Department*

**Purpose**—The purpose of this study is to develop a modular wrist/hand and finger orthosis system that meets the requirement and demand for immediate "on the spot" orthosis supply and to improve function and comfort. Tayside Rehabilitation Engineering Services have, over the last two years, been developing a system to meet this criteria.

**Progress**—A series of 90 thermoplastic forearm hand and finger interface modules and interconnecting dynamic and static components have been produced. These components can be variously inter-

connected to produce a range of orthoses capable of providing the following single or collective functions: 1) Wrist—dynamic wrist extension assist/flexion resist; 2) Thumb—a) dynamic thumb abduction; b) static thumb opposition; c) free thumb motion; 3) MCP's—a) dynamic MCP extension assist/flexion resist; b) dynamic MCP flexion assist/extension resist; c) static MCP positioning; and, 4) PIP—PIP extension assist/flexion resist. All components are attached interconnected by a single size of socket head screw, thus only a hex driver is required for system assembly and adjustment.



**Preliminary Results**—The system has been used in-house for approximately the last year-and-a-half, and has proven satisfactory in terms of versatility and functional control. Sufficient components have now been manufactured to facilitate a four center independent system evaluation. The essential assembly and fitting manual has been completed.

**Future Plans**—A prototype multiangular, adjustable static wrist joint mechanism has been developed and is currently undergoing evaluation. Similarly, an additional module to provide adjustable control of interdigital alignment and prevent finger drift in

rheumatoid patients is currently being developed. The work on these components is soon to be concluded. Independent clinical trials will commence within the next two months; findings will be collated next summer.

Transfer of designs and information to facilitate the commercial manufacture of the system was recently completed, and marketing by Hugh Steeper, Roehampton, Ltd., is imminent.

#### **Publications Resulting from This Research**

**None reported.**

# III. Total Joint Replacement and Other Orthopedic Implants

*For additional information on topics related to this category see the following Progress Reports: [287], [296], [335], [376].*

## A. General

### [54] Skeletal Attachment of Prostheses

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A487-RA)*

**Purpose**—This project attempts to create an analog of a fixed bridge attached to an implant in the mandible or maxilla by creating a mucocutaneous transition zone from periosteum to skin with a vascularized small bowel transplant over a stainless steel implant in the tibial isthmus.

**Progress**—The sheep as a model has been evaluated, and surgical and anesthetic techniques, including microvascular reanastomosis of the portal vein and artery to the tibial vein and artery, have been developed and refined. A stainless steel four-fluted self-tapping implant has been manufactured in a range of sizes. Friction attachment techniques for the prosthesis have been developed and are being refined. Postoperative care regimens include antibiotics, analgesics, a pylon prosthesis immediately post-op, and immobilization in a sling allowing full weightbearing.

**Results**—Six sheep were operated on in a preliminary phase. Mechanical and histological studies of these implants revealed a surviving glandular mucosa at 6 weeks, and no infection or loosening. Nine sheep ranging from 65 to 95 kg have been so treated, and initial results indicated a stable and functioning implant and prosthesis. By eight weeks,

an apparent osteomyelitis caused a sequestration of the implant. Histological study of the transplant revealed a viable bowel segment.

Revision of the technique has been undertaken in view of the development of osteomyelitis. Omental pedicles have been passed through the external inguinal ring subcutaneously to the amputation site as a potential infectional barrier. Initial results suggest less bone reaction and healthier animals.

**Future Plans/Implications**—It is clear that the periosteum is a key to maintaining the integrity of the implant, and that the stomal construction is a highly important factor. Redesign of the implant to make coverage of the intramedullary canal with periosteum possible will be undertaken. Development of the stomal architecture with a silastic implant will also be undertaken. Ultimately, the tibial implant will be revised to allow transfer of muscle force and displacement from an intra-tendinous ingrowth device to a prosthesis-activating attachment.

#### **Publications Resulting from This Research**

None reported.



## [55] Fracture Healing and Bone Remodeling in Plated Long-Bones

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A294-2RA)

**Purpose**—The objectives of this study are to develop models of the fracture-healing process for both conservatively-treated and internally-plated long-bone fractures.

**Methodology**—Both mathematical and experimental models of fracture healing are used to study the fracture-healing process. The mathematical models utilize the finite element technique. Models of conservatively-treated long-bone fractures and plated long-bone fractures have been developed. An osteogenic index is used to predict the regions of a fracture callus which will ossify first.

Laboratory models will be used to assess the efficacy of using shortened screws at the outer screw locations compared with using full-length screws for plated fractures. A strain-gauge-based torque-measuring screwdriver has been designed to monitor the insertion and removal torque of the screws which attach the fixation plate to the bone.

**Results**—Finite element models of plated long-bones show that slippage between the plate and the bone influences, to a great extent, the amount of stress shielding. Plate slippage is a direct function of screw tightness. A time-dependent, incremental remodeling program has been developed to predict the changes in density distribution caused by the implantation of orthopaedic implants. Preliminary models of non-plated long-bones subjected to bending, axial, and torsional loads have been analyzed.

In the experimental phase of the study, plates have been applied to phenolic tubes modeling the human radius. Strain gauges have been applied to

the tubes to monitor strains during loading and unloading. Screw tightness will be determined before and after testing using the strain-gauge screwdriver. The use of shortened end screws versus full-length end screws will be compared.

**Future Plans**—Future plans include the use of the strain-gauge-based screwdriver in surgery to compare insertion and removal torques of plated forearm fractures. It is anticipated that low values of removal torque will indicate that stress shielding is minimal and the risk of refracture will be low.

The use of an incremental remodeling program will allow the prediction of changes in the density distribution caused by plate fixation.

### Publications Resulting from This Research

**Stresses in Plated Long-Bones—The Role of Screw Tightness and Interface Slipping.** Beaupre GS, Carter DR, Orr TE, Csongradi J, *J Orthop Res* 6:39-50, 1988.

**A Biomechanical Assessment of Plate Fixation, with Insufficient Bony Support.** Beaupre GS, Carter DR, Dueland RT, Caler WE, Spengler DM, *J Orthop Res* 6:721-729, 1988.

**Finite Element Predictions of Long-Bone Remodeling.** Beaupre GS, Carter DR, in *Proceedings, ICAART 88*, Montreal, 482-483, 1988.

**Correlations Between Mechanical Stress History and Tissue Differentiation in Initial Fracture Healing.** Carter DR, Blenman PR, Beaupre GS, *J Orthop Res* 6:736-748, 1988.

**A Bone Surface Area Controlled Time-Dependent Theory for Remodeling.** (Abstract) Beaupre GS, Carter DR, Fyhrie DP, Orr TE, *Trans Orthop Res Soc* 14:311, 1989.

**Role of Mechanical Loading in the Progressive Ossification of a Fracture Callus.** Blenman PR, Carter DR, Beaupre GS, *J Orthop Res* 7:398-407, 1989.

**Fracture Healing Patterns Calculated from Stress Analyses of Bone Loading Histories.** (Abstract) Blenman PR, Carter DR, Beaupre GS, *Trans Orthop Res Soc* 14:469, 1989.



## [56] Bone Ingrowth and Remodeling with Porous-Coated Implants

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Sponsor: *VA Rehabilitation Research and Development Service (Project #A501-RA)*

**Purpose**—The purpose of this work is to formulate a comprehensive theory consistent with many features of skeletal growth and development, maintenance, regeneration, and degeneration. The results of our previous investigations indicate that tissue-stress histories play a major role in regulating the biology of skeletal tissues and that these influences are stronger and appear earlier in skeletal development than previously has been thought. The equations used to predict cartilage, bone, and mesenchymal tissue biology are similar to those that account for mechanical energy dissipation or the accumulation of fatigue damage in all materials. Our results may thus reflect fundamental characteristics of the transduction of mechanical energy to chemical energy in living organisms. The context in which this work is being conducted is porous-coated/bony ingrowth prosthetic replacement of the proximal femur and tibia. The end product of this research will be a consistent framework of computer analyses which can be applied to predict the biological events associated with initial ingrowth and subsequent bone remodeling. We anticipate that it will be possible to apply these approaches to the design and evaluation of any implant in the body.

**Methodology**—In the course of our investigations, we will generate three-dimensional finite element models of the proximal femur and proximal tibia. The loading history over some period (e.g., an "average" day) will be specified by a series of discrete load cases applied for a specific number of load cycles. The entire bone will initially be represented by a solid, homogeneous structure with a constant bone density.

Using a time-incremental bone remodeling technique, we will remodel the bone computer models to create an internal distribution of bone density and morphology which conforms to our bone remodeling theory. The resulting prediction of bone density

distributions will be compared to those measured from cadaver specimens. Our theory and computer approaches may then be modified so that our predictions correlate better with normal bone anatomy.

The proximal tibia and femur models will then be altered to represent the initial implantation of various uncemented porous-coated components. A thin layer of pluripotential tissue will be represented at the bone/prosthesis interface. The multiple loading stress history approach will then be applied and the differentiation of the interface tissue will be predicted. Using different stress history criteria, we will thus predict the extent and locations of bone ingrowth along the interfaces. Our criteria will be adjusted and varied parametrically to represent the types of results which have been observed by others in experimental animal studies and clinical retrievals. Subsequent bone remodeling around the prostheses will be calculated using the same algorithms which had been previously verified for the normal tibia and femur.

**Future Plans**—It is apparent that some design features may provide good initial fixation and encourage bone ingrowth yet lead to subsequent bone remodeling which is deleterious. We will be able to address this issue with computer methods and thereby achieve a broad perspective of the overall implications of various design features.

We anticipate that from the analyses we perform, certain design features will begin to emerge which will suggest the evolution of cogent design principles for bony ingrowth total-joint replacement. The proposed work represents a melding of basic and applied research. Our theoretical approach to the regulation of skeletal tissue by mechanical stresses will be explored and refined while it is being applied to solve immediate design problems which have a direct clinical impact.



### Publications Resulting from This Research

**Applications of a Bone Remodeling Theory to Femoral and Tibial Prosthetic Components.** Orr TE, Beaupre GS, Fyhrie DP, Schurman DJ, Carter DR, *Trans Orthop Res Soc* 13:100, 1988.

**Computer Predictions of Bone Remodeling Around Implants.** Carter DR, Orr TE, Beaupre GS, Fyhrie DP, Schurman DJ, *Orthop Trans* 12:345, 1988.

**A Bone Surface Area Controlled Time-Dependent Theory for Remodeling.** Beaupre GS, Carter DR, Fyhrie DP, Orr TE, *Trans Orthop Res Soc* 14:311, 1989.

**Femoral Bone Architecture Computed from 3-D Models Relating Bone Remodeling to Stress Histories.** Orr TE, Beaupre GS, Carter DR, in *Proceedings of the 12th International Congress of Biomechanics*, 167, 1989.

**Computer Predictions of Bone Remodeling Around Porous-Coated Implants.** Orr TE, Beaupre GS, Carter DR, Schurman, DJ, *J Arthroplasty* (accepted for publication).

## [57] Effects of Treatment for Heterotopic Bone Formation on Biological Fixation

**Stephen D. Cook, PhD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A450-RA)

**Purpose**—The purpose of this study is to evaluate the effects of several combinations of short-term and chronic indomethacin therapies on the amount of bone growth into a porous surface as well as the bone-porous implant attachment strength.

Ectopic ossification following total hip arthroplasty is a frequently reported complication, with occurrences ranging up to 62 percent. Clinical use of indomethacin has been shown to be effective in reducing ectopic bone formation. However, since indomethacin is also used as an anti-inflammatory drug in several patient groups, the question arises as to what duration and at what period postoperatively does indomethacin usage prohibit effective bone-porous implant attachment.

**Methodology**—The animal model in use is the skeletally mature adult mongrel canine ranging in weight from approximately 18 to 22 kg. Using aseptic techniques, cylindrical Ti-6Al-4V alloy implants 5.1 mm in diameter by either 18 mm or 20 mm length, coated with 1 mm thick spherical bead Ti-Al-4V alloy porous coating are placed in the femoral bone through both cortices. Each animal receives five or six implants bilaterally. After 3, 6, 12, 18, or 24 weeks, the implants are harvested and subjected to mechanical push-out testing to determine interface attachment strength. Intact and tested samples are also evaluated using standard undecalcified histologic techniques.

Animals were randomly assigned to the following groups: 1) controls (no drugs), implantation periods of 3, 6, 12, 18, and 24 weeks; 2) indomethacin given each day for 2 weeks preoperative and for 6 weeks postoperative, implantation periods of 3, 6, 12, 18, and 24 weeks; 3) indomethacin immediately postoperative and each day until sacrifice, implantation periods of 3, 6, 12, 18, and 24 weeks; 4) indomethacin each day beginning 3 weeks postoperative until sacrifice, implantation periods of 6, 12, 18, and 24 weeks; 5) indomethacin each day beginning 6 weeks postoperative with sacrifice, implantation periods of 12, 18, and 24 weeks; 6) indomethacin each day beginning 9 weeks postoperative until sacrifice, implantation periods of 18 and 24 weeks; and, 7) indomethacin each day beginning 18 weeks postoperative until sacrifice, implantation period of 24 weeks.

All animals receive 1.0 mg/kg/day of indomethacin orally in 2 divided doses. Blood is drawn at regular intervals during therapy to confirm blood indomethacin levels.

The animal (drug) groups and time periods will allow assessment of the following clinically relevant questions: 1) Does indomethacin given strictly postoperatively affect ingrowth to the extent previously reported? 2) Does the delay in starting indomethacin therapy (3- to 18-week delay) have a consistent effect of increasing attachment strength? and, 3) How soon after surgery can indomethacin therapy

be started and not affect ingrowth? In addition, the time period postoperatively at which indomethacin exerts an effect, and the duration of indomethacin therapy which causes an effect may also be determined.

#### Publications Resulting from This Research

None reported.

### [58] Effect of Surgical Fit on the Biological and Mechanical Response to Porous-Surfaced Implants

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Sponsor: VA Rehabilitation Research and Development Service (Project #A136-3RA)

**Purpose**—Ideally, a porous-surfaced implant relying on bone ingrowth fixation should make initial apposition with the surrounding bone. Unfortunately, this is not always achieved surgically at all locations; thus, a space between the implant and bone is present. This space may be the result of deficiencies in instrumentation design, implant design, or surgical technique. The gap may severely alter the type, amount, and rate at which tissue infiltrates the porous-implant surface. Thus, the achievement of significant fixation strength may be delayed or ultimate attachment strength affected. A model to study the effect of such gaps on the quantity and quality of bone growth into a porous-surfaced implant in both the cancellous and cortical bone regions has been developed. It will be used to study these parameters, including the interface attachment strength.

**Methodology/Results**—Implants were surgically placed in the intramedullary canals of adult dogs,

producing uniform gap space 0.0-2.0 mm wide. Histologic and microradiographic evaluations were conducted after 3, 6, and 12 weeks *in situ*. The results demonstrate that the initial apposition of a porous implant to the surrounding bone surface is not necessary for fixation by bone ingrowth. New bone will grow up to and within the porous structure of an implant even when there is a gap as large as 2.0 mm. However, the rate and degree of maturity and mineralization is enhanced when the gap width is 0.5 mm or less. The amount of bone activity in the cortical region was greater than in the cancellous region at 3 and 6 weeks after operation. After 12 weeks *in situ* bone growth in gap spaces and into the porous coating was approximately equal.

#### Publications Resulting from This Research

**Tissue Response to Porous-Coated Implants Lacking Initial Apposition.** Sandborn PM, Cook SD, Spires WE, Kester MA, *J Arthroplasty* 3(4):337-346, 1988.

### [59] Relationships Between Canal Fill and Interfacial Displacement for an In Vivo Loaded Porous Ingrowth Femoral Prosthesis

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Sponsor: VA Rehabilitation Research and Development Service (Project #A356-RA); Richards Medical Co.

**Purpose**—Relative displacement at the bone-implant interface is a critical factor in the successful fixation of porous ingrowth prostheses. This study presents, for the first time, data from a quantified animal model relating the interfacial displacement at the

bone-implant interface to the actual canal fill after three weeks of functional loading *in vivo*.

**Progress/Methodology**—The prosthesis was a collarless Ti-6Al-4V straight-stemmed design. A CP



Ti orderly-oriented wire mesh was sintered onto the proximal anterior and posterior surfaces. Unilateral surgery was performed by reaming the canal to a standard size and using 1 mm undersized broaches. Upon retrieval, micromotion at the bone prosthesis interface was derived from six Linear Variable Displacement Transducers (LVDT) placed between two plates attached to the femoral head and shaft. The reconstructed femora were loaded cyclically from 0.1-1x body weight at 1 hz. The loads were applied at 21 degrees in the coronal plane simulating mid-stance. The maximum displacements were calculated in the vertical, horizontal medial-lateral, and horizontal anterior-posterior directions.

The femora were sectioned into 6-8, 5 mm specimens, and contact radiographs were made which were used to quantify the fit and fill of the prosthesis within the femoral canal with the Zeiss IBAS image analysis system. Fit was defined as the apposition of a contour of the endosteal surface of the femur with a contour of the outer surface of the prosthesis expressed as a percentage of the length of the endosteal surface. Fill was defined as the percent of the medullary canal occupied by the prosthesis. These data were then correlated with the mechanical testing data.

**Results**—The data for the canal fill in the three-week dogs revealed an average proximal fill of 48.3 percent, distal fill of 79.9 percent, and average fill of 64.1 percent. The data for canal fit were found to

be highly variable and did not correlate with the mechanical testing data.

In contrast, the fill data revealed that a linear relationship exists between canal fill, and both vertical and horizontal medial-lateral micromotion. This relationship was the strongest with proximal canal fill with  $r = -0.92$  and  $p = 0.001$ . No correlation was noted between canal fill and micromotion in the anterior-posterior plane as testing in this direction was extremely sensitive to the orientation of the prosthesis to the applied load.

In this study, the actual canal fill was determined for each prosthesis tested. We established a statistically significant linear relationship between canal fill and reduced micromotion. Retrieval three weeks after implantation was used to allow full stress relaxation *in vivo*, and a brief period of loading prior to significant bone ingrowth. Poor correlation between canal fit and stability was related to shifting of the prosthesis within the canal during sectioning. Proximal fill yielded a stronger correlation with reduced micromotion compared with distal canal fill, probably due to the wedging of the prosthesis within the proximal canal, and the distal canal functioning as a contact point in three-point fixation.

#### **Publications Resulting from This Research**

None reported.

## **[60] Enhancement of Union of Segmental Defect Fractures II**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A278-RA)

**Purpose**—This study originated to investigate the potential for enhancement of bone union in defect fractures using both progressive loading of the fracture site and various types of bone graft materials. Originally, synthetic and alternative bone graft materials were suggested as potential treatment for these severe fractures. Since then, an alternative method developed in Russia, consisting of bone transfer to allow healing of segmental defect fractures, has been shown to be possible.

Unfortunately, there is little information available outside the USSR regarding this significant new mode of therapy. There are many questions in the United States regarding this new treatment method, including: Does it work? How does it work? How fast may bone be transported? Is neovascularity occurring through periosteal or extraperiosteal vessels, or does it come through endosteal blood supply? Can the device be used for lengthening of an extremity as well as for treatment of segmental



defects? Does the method have to be done using wires on tension, or can it be performed using larger pins that are more available in the United States? and, What is the effect of bone scans or magnetic resonance imaging (MRI) during the course of this therapy?

**Methodology**—We have previously defined a bilateral segmental defect dog model which has been used to study methods of obtaining union or enhancing union in segmental defects. This has proved to be a consistent and reliable model and will be used to continue work on the Ilisarov method of transfer to enhance union, as well as to finish previous work on the effect of progressive load-sharing and segmental defect healing.

Our work is divided into two phases: Phase One is centered on the Ilisarov method for bone transfer. We will evaluate: 1) the biomechanics and histomorphometry of defect fracture healing using the Ilisarov method as compared to autogenous cancellous bone graft (fracture strength, stiffness, energy absorption at the fracture, and various histomorphometric parameters); 2) the critical nature of the corticotomy used to begin the transfer using various methods; 3) the ideal speed or rate of bone transfer and its effect on new bone formation (regenerate bone); or, 4) the use of this method for lengthening of extremities, in addition to simply enhancing union by attempting to lengthen the dog forelegs. An attempt will be made to transfer these bone segments over an intramedullary device following reaming in an to attempt to determine whether the blood supply comes from periosteal or endosteal blood vessels to create this new bone formation; 5)

external fixators created for this method using small wires (1.5 mm) on tension or larger pins (4-5 mm) more familiar in the United States; and, 6) the effect of bone scans and MRI's on this method to determine the endpoint of union or rate of transfer.

Phase Two will finish work begun on the effect of progressive load-sharing in segmental defect healing. The same dog model will be used to study the effect of progressive load-sharing. The graft material on both sides of the defect will be cancellous bone. On one side, a nonvariable-rigidity external fixation system will be applied similar to that used to define the original defect model. Contralaterally, an external fixation system allowing controlled axial displacement will be applied. It will otherwise be identical in configuration to the nonvariable device. This device has been developed. It allows controlled axial displacement using wave springs in the midportion of the external fixation frame. Since the stiffness of the callus and the displacement allows for control of the maximum force applied to the callus, the force applied can be altered by changing the number of wave springs in the midportion of the apparatus, making the device more or less rigid. The load applied at the fracture site will be progressively increased as fracture callus stiffens.

**Future Plans**—The biochemical, biomechanical, and histomorphometric results of the two methods of fixation will be compared statistically to test for significant differences.

#### **Publications Resulting from This Research**

None reported.

### **[61] Evaluation and Examination of Retrieved Porous-Coated Orthopaedic Prostheses**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A473-DA)

**Purpose**—The overall objective of this study is to assess the long-term feasibility of porous coating as a mechanism for fixing orthopaedic prostheses to bone. This examination of clinically-retrieved, porous-coated hip and knee prostheses will assess the

importance of such variables as material composition (cobalt and titanium-based alloy systems), design (implant geometry), location of porous coating on the prosthesis, coating pore size, pore geometry, pore density, and surface roughness on



the resulting interface between the prosthesis and bone. The study will address the issues of stress shielding, ion release and wear debris formation and, where possible, clarify causal relationships with prosthesis parameters.

**Progress**—In the first year of this project, we have received and examined 259 retrieved, porous-coated hip and knee prosthesis components. One hundred and twenty-six of these were retrieved hip prostheses, 123 were knee prostheses.

**Results**—We have seen bone ingrowth of femoral hip and femoral knee prostheses with both the largest and the smallest pore sizes currently available, indicating that pore size alone is not a controlling variable to bone ingrowth in the available size ranges. Titanium mesh, titanium beaded systems, and titanium plasma-sprayed systems were compared to cobalt alloy beaded systems to determine whether the appearance or amount of bone ingrowth of devices with these types of coatings differed one from another. Bone ingrowth of the beaded and wire mesh systems were seen and direct bone contact to the plasma-sprayed surface was observed. No differences in the appearance of bone ingrowth of cobalt alloy versus titanium systems were noted.

Bone ingrowth of femoral hip prostheses, femoral knee prostheses, and patellar prostheses was frequently seen. Bone ingrowth of acetabular prostheses was much less frequently seen, and bone

ingrowth of tibial prostheses was seen least frequently of those device types evaluated. Tibial prostheses with porous-coated central pegs demonstrated bone ingrowth of the central peg more frequently than ingrowth of the porous-coated plateau. The most frequent bone ingrowth of the underside of the tibial plateau was seen with prostheses fixed with four metal screws. However, there was generally evidence of metal fretting between the screws and the screw holes and the local tissue had often turned black. Metal ion concentrations in this tissue was measured as greater than one percent by weight in several cases.

Worn polyethylene articular surfaces and the development of significant amounts of polyethylene wear debris was seen in a high percentage of knee prostheses. Mechanisms of failure of patellar and tibial components included: separation of polyethylene from the metal backing, wear-through of the polyethylene, cracking, pitting, and delamination of the articulating surface, as well as deformation of the polymer due to creep. Examination of the ingrowth surfaces of tibial and patellar prostheses which had been retrieved for reasons of polyethylene failure often demonstrated polyethylene wear debris at the margins of the porous coating which appears to be associated with localized osteoclastic activity and bone resorption.

#### **Publications Resulting from This Research**

None to date.

## **[62] Evaluation of Cartilage Grown from Rib Perichondrium**

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**Sponsor:** *National Institute of Arthritis and Musculoskeletal and Skin Diseases, National Institutes of Health*

**Purpose**—The purpose of this research is to investigate the use of perichondrial grafts in articular cartilage defects and to characterize the newly-formed cartilage. The goal is to achieve a clinical biologically acceptable result from perichondrial transplantation.

The long-term failure rate of total joint replacement makes it an unsuitable selection for the treatment of arthritis in the young and middle-aged

patient. A more appropriate treatment for such patients would be a procedure that restores the joint surfaces back to their normal state within biologically-competent tissues.

**Methodology**—In a rabbit model, rib perichondrium was used to repair full-thickness defects in the femoral condyle. The quality of repair was evaluated at 6 and 12 weeks after grafting, using

histological and biochemical methods, including determination of the glycosaminoglycan and total collagen contents and collagen typing. Unacceptable results were obtained in 50 percent of the rabbits. Grafts were unsuccessful in one of two ways: either the graft failed to proliferate (20 percent), or proper attachment of the graft did not occur (20 percent). If the defect was filled with firm, cohesive cartilaginous tissue, the procedure was considered successful.

**Results**—Experiments showed that grafts can proliferate to fill the full-thickness defects in articular cartilage with a neocartilage that has biochemical characteristics similar to those of hyaline cartilage; that is, high content of Type II collagen and glycosaminoglycans. At 12 weeks, the grafts had gained basal attachments and the clefts in the interface between the graft and adjacent tissue were smaller, demonstrating the advantages of using living biological material, which is able to incorporate and remodel.

**Future Plans/Implications**—It has been demonstrated that rib perichondrium transplanted into a

joint will proliferate to form a hyaline cartilage, and that this neocartilage continues to mature until it is almost identical to the tissue it is replacing. Even though a reasonable number of biologically acceptable graft procedures can be performed, it is clear that the techniques of graft fixation will have to be improved, and other methods will have to be explored.

Perichondrial grafts have the capacity to generate cartilage, but differentiation of this tissue into hyaline cartilage is dependent on extrinsic influences. The presence of motion, low oxygen tension, and absence of vascularity could favor and maximize its development. Localized articular-cartilage lesions such as osteochondritis dissecans or osteonecrosis of the femoral head may be treatable by grafting with perichondrium. Limited lesions of osteoarthritis or osteoarthritis of small joints may also be amenable to this treatment.

#### **Publications Resulting from This Research**

None reported.

### **[63] Development of a Percutaneous Access Device from a Porous Carbon Material**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Our present study has the following objectives: 1) to examine whether percutaneous devices fabricated from porous vitreous carbon can function satisfactorily *in vivo* over extended periods; and, 2) to determine whether the interface formed between dermal tissue and porous carbon devices is capable of preventing the infiltration or colonization of bacteria present at the implant site.

**Methodology**—Porous carbon percutaneous implant devices were surgically implanted in pigs and rabbits and monitored over periods of time ranging from 2 weeks to 24 months for signs of infection or rejection including swelling, heat, tenderness, redness, or

evulsion. A series of bacterial colonization experiments was performed at the tissue/implant interface, using *S. aureus* and *E. coli* as the topical inoculate. *In vitro* attachment studies were also done using 1 mm thick slices of the carbon material soaked with stained bacteria which were subsequently rinsed and examined under an epifluorescent microscope.

**Progress**—We completed a series of bacterial colonization experiments in rabbits. An Investigational Device Exemption application was submitted and approved by the Food and Drug Administration to begin using the implant device in human subjects.



Approval for human subject implantation trials was also granted by the Baylor College of Medicine Investigational Review Board.

**Results**—Histopathology demonstrates dense tissue ingrowth into the porous carbon implants with stabilization occurring at approximately 7 weeks. Implants have been maintained up to 24 months in pigs and rabbits, showing no clinical signs of infection. *In vitro* attachment studies showed a uniform binding of bacteria to the carbon. In spite of this finding, *in vivo* bacterial colonization studies found that regardless of an initially high rate of colonization after inoculation, the skin/implant interface resists infection by both normal and pathogenic bacteria.

**Future Plans**—Human implantation trials will begin immediately, using 10 subjects. Porous carbon implants will be percutaneously implanted in the axilla region, dorsal to the pectoral muscle. Implants will be maintained for 6 months or until there is clinical indication for removal; i.e., infection, evulsion, or persistent discomfort.

#### **Publications Resulting from This Research**

**Bacterial Challenge Study of a Porous Carbon Percutaneous Implant.** Krouskop TA, Brown HD, Gray K, Shively J, Romovacek GR, Spira M, Runyan RS, *Biomaterials* 9:398-404, 1988.

### **[64] Interface Strength and Histology of Expandable Titanium Implants**

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**Sponsor:** *National Institute of Dental Research, National Institutes of Health*

**Purpose**—The specific aim of this study is to determine the correlation between histologically-definable osseointegration and mechanically-tested shear interface strength of commercially pure, expandable, smooth surface titanium implants.

Expandable endosseous implants exert favorable compressive stresses that provide an environment that enhances bone growth onto the prosthesis. Expansion against bone replaces the need for technique-sensitive steps, such as threading and tapping, which may lead to failure when not precisely adhered to. The long-term objective is to demonstrate that expandable implants exert an optimal applied compressive level that improves the prognosis of osseointegration, thereby improving the reliability of complete bony union, and shortening the healing period prior to complete osseointegration. This will provide greater predictability for a successful functional implant.

**Methodology**—Cylindrically-shaped implants whose diameters increase uniformly when expanded are

surgically implanted in femurs of rabbits. Control implants of the same configuration are subjected to the same implantation techniques. Two different time periods are selected to examine the change in healing and osseous interface that can resist push-out over time. Bone modeling will be observed for implants having three different internally applied loads (sub-optimal, optimal, and supra-optimal). The amount of osseointegration will be assessed directly by selected histologic samples and predicted indirectly by the relative level of interface strength. Implantation techniques will follow the principles recommended by P-I. Branemark. Histologic samples will be decalcified and prepared for sectioning before observation under the light microscope. The shear interface strength will be measured on a Materials Testing Systems instrument.

#### **Publications Resulting from This Research**

None reported.

## [65] Chevron Osteotomy with Biodegradable Fixation for Hallux Valgus

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Sponsor: *University of Technology, Institute of Plastic Technology, Tampere, Finland*

**Purpose**—The general intention is an immediate mobilization after a Chevron osteotomy by use of a biodegradable implant when operating for hallux valgus.

**Methodology**—The Chevron osteotomy is fixated with a biodegradable implant (Biofix rod, diameter 2 mm, length 25 mm). The implant is mainly composed of self-reinforced polyglycolic acids (PGA). PGA is metabolized via a tricarboxylic acid cycle and gradually expelled through the lungs as water and carbon dioxide during approximately 3 to 4 months.

The foot is dressed in sterile foam-pads and an elastic bandage, and the patient is immobilized immediately after the operation.

**Preliminary Results**—After treatment of 60 feet using this method, the preliminary results showed that 59 patients were radiologically healed six weeks postoperatively without any secondary dislocation. The patient who did not heal showed indications of osteitis and was treated with antibiotics. The diagnosis was not verified by a bonescan.

**Future Plans**—Observations have not lasted long enough to evaluate the qualification of this method in the long run. All patients will have their walking ability tested by dynamic elastic response (DER).

### Publications Resulting from This Research

**The Development of Chevron Osteotomy.** Andersen S, Jacobsen K, Baadsgaard Sorensen K, *Acta Orthop Scand* S227(59):19, 1988.

## B. Hip

### [66] Epiphyseal Hip Replacement: A Pilot Study

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Sponsor: *VA Rehabilitation Research and Development Service (Pilot Project #B987-PA)*

**Purpose**—Conventional total hip joint replacement is a highly successful surgical procedure for treatment of severe arthritis of the hip. However, the incidence of mechanical failures in the form of femoral component loosening and stem fracture has become an increasingly significant problem, especially in younger patients.

This has renewed interest in conservative alternatives. One such alternative is our epiphyseal replacement prosthesis, a new research-based design which incorporates the interface contours suggested

by the geometry of the epiphyseal plate or scar. We will implant the prototype epiphyseal replacement prostheses in animal subjects to determine the efficacy of this design.

**Methodology**—Using engineering design and finite element analysis techniques, we have attempted to improve on the generic type of hip surface replacement by critical design changes which appear to be of major benefit on a theoretical basis. Animal experimentations involving the implantation of pro-



tototype prostheses will be performed in order to clear the way for application to human subjects.

This study will be an *in vivo* biological and clinical evaluation and should verify the theoretical model. The animal project consists of implanting the epiphyseal surface hip replacement prosthesis into eight adult male sheep—one per sheep. (This is the smallest number of animals that can give us the answer to efficacy.) All eight prostheses will be placed for bony-ingrowth fixation. Four of the animals will be sacrificed at six weeks, at which time the extent of bony ingrowth can be gleaned. The other four sheep will be sacrificed at six months: following this, adaptive bone remodeling due to the stress environment will be studied. Temporal bone changes will be assessed using tetracycline labels, radiographic methods, and fluorescent histomorphometric techniques of undecalcified sections. At the time of sacrifice, the proximal femur and hemipelvis will be extracted and contact X-rays made. Thereafter, microradiographs of ground-coronal sections and histologic specimens will be evaluated for bone ingrowth and remodeling. Comparisons will be made from our experimental results and those of the literature with other prostheses.

**Progress**—Surface replacement prostheses have been designed with a bone/prosthesis interface that

closely follows the lines of the epiphyseal growth plate of the proximal femur of the sheep. The prostheses will be made of titanium and will be fixed to the femoral head through the use of bony-ingrowth surfaces. A set of 1.5 mm diameter spikes are incorporated into the prosthesis at the bone/prosthesis interface to provide firm initial fixation and to prevent micromotions of the prosthesis which can inhibit bony ingrowth. Simple instrumentation has also been designed for implant installation.

The sheep and all necessary surgical and histological supplies and equipment have now been ordered. The prostheses and accompanying instrumentation are currently being manufactured by the Zimmer Corporation of Warsaw, IN.

**Implications**—It is expected that the results of this pilot animal study will provide the basis for a full-scale development study in which the initial prototype will be redesigned through further animal testing and finite element studies, eventually leading to the development of a surface hip replacement prosthesis, along with the necessary instrumentation, which will be implanted in human patients.

#### **Publications Resulting from This Research**

None reported.

### **[67] Quantitative Analysis of Total Hip Arthroplasty on Stress and Strain**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A100-3RA)

**Purpose**—New acetabular and femoral component designs and implantation techniques are continually evolving in an attempt to improve the overall performance of total hip arthroplasty. Little quantitative information has been available concerning the effect of implantation of these devices on the pelvis and femur as compared to the natural hip joint. Historically, this project has used strain gauge instrumentation in the evaluation of pelvic strain changes following implantation of various acetabular cup designs with varied techniques. More recently, evaluation of optical methods for strain

change determination have been addressed to aid in this evaluation. The basic premise for the research program is to evaluate whether bone strain changes might be predictive of long-term success or failure of the arthroplasty should isoelastic reconstructions be affected.

**Progress**—Following early work which led to the development of automated computerized data acquisition systems and fixtures, assessment of various implantation techniques, and acetabular prosthesis designs on pelvic medial wall strain during simulated



single limb stance were recorded. Techniques including the effect of pilot holes, subchondral bone reaming, cement restrictors, and spacers were evaluated. More recently porous-coated, noncemented implants and "screw-in" cobalt chrome implants have been evaluated. Additionally, optical holographic interferometric methods have been utilized to look at the effect of femoral components with a different quality of fit on femoral strain.

**Results**—Results indicate that pilot holes and substantial reaming lead to large increases in pelvic strain per unit load while uniform cementation leads to minimal changes when the compliance of the component itself is appropriate. Evaluation of various cup designs as they relate to implant compliance and their effect on pelvic strain have also been determined.

When extremely low compliance components such as polyethylene are utilized, increases in pelvic strain are considerable while very thick cobalt-chrome-metal-backed components lead to strain decreases or protection. Those implants of intermediate compliance, e.g., titanium or thin cobalt-chrome, lead to marginal strain increases. With the evaluation of noncemented cobalt-chrome implants, it was found that considerable initial strains were being generated during the insertion process. Additionally, new designs of metal-backed porous components have been evaluated and they confirm that strain changes in the pelvis may be controlled with the control of implant compliance in insertion methodology.

## [68] Rehabilitation Implications of In Vivo Hip Pressure Measurements

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A352-2RA)

**Purpose**—Patient management in recovery and rehabilitation following hip surgery has not benefited from quantitative *in vivo* data on the actual pressures occurring in the joint. An instrumented endoprosthesis which telemeters pressure at up to 14 discrete locations on load-bearing acetabulum cartilage 250 times a second has achieved such data for

Evaluation of press-fit noncemented femoral components using holographic interferometry has shown that qualitative changes in strains may be evaluated using these methods. Discontinuities in slope were found at the distal tip of the prostheses, thus indicating areas of increased strain. Difficulties in quantification of this information has led to the utilization of speckle-shearing interferometry (SSI) as a new optical method for evaluating both "in- and out-of-plane" strains. Early results using these methods are promising.

**Future Plans/Implications**—The initial investigations have shown that optical techniques provide a useful noncontact method for biomechanical analysis if careful processing is followed. Qualitative results using SSI are encouraging and indicate that this method should be an effective approach to evaluation of biomechanical strains. Comparison of SSI with finite element analysis techniques show good correlation in a standardized plexiglass model which was created to ascertain system accuracy. Computerized analysis methods of SSI images will be developed in the future to allow for quantitative evaluation of the effect of implantation of femoral components on surrounding bone strain in hopes of providing insights into subsequent *in vivo* performance.

### **Publications Resulting from This Research**

None reported.

over four years, commencing in the operating room, through recovery, all phases of rehabilitation, and during many activities of daily living including walking, jogging, jumping, stair climbing, and descending and rising from chairs of varying height.

The data thus far substantiate some patient management procedures and daily activities and



raise serious questions as to the appropriateness of other common maneuvers. Trends in the data for the same action define quantitatively when normal capability has been regained. The extant data are also influencing local surgical practice, not only for endoprostheses, but for total joint replacement as well. Clearly, data from similarly-implanted patients must be achieved and compared before specific recommendations for patient management, activity protocols, and surgical practice can be advanced.

We plan to implant six additional instrumented prostheses and acquire pressure (and prosthesis temperature) data from surgery through recovery, rehabilitation, and into normal activity. During all movement paradigms, starting in rehabilitation, the pressure data will be complemented with complete kinematic and dynamic gait data, and for some experiments, with electromyographic activity.

Data acquisition, processing, and interpretation will address these research questions: 1) What are the optimum patient management protocols during recovery and rehabilitation? How does joint pressure respond to muscle contraction during different rehabilitation modes? When can the patient's reha-

bilitation with respect to specific actions (i.e., walking, rising from a chair, etc.), be considered completed? 2) Will pressure readings over time, in connection with other medical and radiographic indications, permit monitoring the frequently experienced tendency of endoprostheses to migrate through acetabular cartilage? Will careful sizing of prostheses to the natural acetabular diameter reduce or eliminate this tendency? 3) Can the transient pressure data (in combination with forceplate and EMG data) elucidate the role of the joint in impact loading, ranging from heel strike in level walking to heel bouncing, and jogging? How prevalent is muscular co-contraction across the joint in such maneuvers?

**Implications**—We are in the unique position to generate *in vivo* data to address these issues—data relevant not only to the many and increasing number of endoprosthesis recipients, but also to the far greater number of those undergoing major hip surgery of various kinds.

#### **Publications Resulting from This Research**

None reported.

### **[69] Optimized Surface Bonding and Stiffness of Femoral Endoprostheses**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A498-RA)

**Purpose**—Loosening of the femoral component is the most common complication of total hip replacement. The objective of this investigation is to determine the optimal surface characteristics and material properties for a femoral endoprosthesis to avoid loosening. The specific short-term objectives are to investigate the following parameters using finite element modeling techniques: 1) the shape of the stem; 2) a presence of a collar for calcar contact; 3) the surface distribution of bone-prosthesis bonding; 4) the elastic modulus of the prosthesis; and, 5) the role of Coulomb friction at the bone-prosthesis interface.

**Methodology**—This investigation employs computer-based mathematical models using displacement-

based finite element techniques. Commercially-available software is used for the core analysis and for graphical pre- and post-processing. Special computer programs are also developed for the representation of nonlinear mechanical behavior at the bone-prosthesis interface.

This investigation also employs new techniques for analysis of various design parameters in conjunction with the finite element models. Iterative solution procedures, based on mathematical optimization, are developed. New nonlinear contact surface algorithms, which include Coulomb friction, are also employed in idealized two-dimensional models.



**Progress**—A three-dimensional finite element model of an intact femur was developed. The model was modified to include a straight-stem anatomical medullary locking (AML) femoral component. Three different bone-prosthesis interface conditions were represented: 1) complete porous-ingrowth; 2) cemented; and, 3) a nonlinear press-fit. The mechanical properties of the prosthesis were also varied.

Two general sets of loading conditions were defined. The first set of loads represent the repetitive loads which occur during gait. The second set of loads represent more extreme conditions which occur less frequently. These loading conditions consist of the peak forces encountered during stair ascent and three other loading conditions which are variations of this loading condition. Computer software was developed for the representation of the nonlinear bone-prosthesis interface. Software was also developed for the determination of loads during various isometric muscle activities.

**Results**—The bone-prosthesis interface properties have a strong influence on the stresses in the supporting bone. Cementing the femoral component results in the most stress protection of the metaphyseal cortical and trabecular bone, followed by the fully-ingrown porous-coated implant, with the press-fit implant resulting in the least stress protection. In the more distal sections, the differences are small. The predicted stress protection in the metaphysis and proximal diaphysis agree with published data.

Reduction of the prosthesis stiffness by changing the material properties results in reduced stress protection of the supporting cortical bone. Use of a carbon fiber reinforced composite material as a substitute for titanium results in roughly the same degree of improvement in terms of stress protection as the improvement seen with the substitution of titanium for cobalt-chromium. Using the model predictions, we have established relationships for the peak cortical bone stresses at particular sections as a function of the modulus of the prosthesis. These equations are in the form of composite beam theory with combined axial and bending loads.

**Future Plans**—The next objective is to develop an iterative solution procedure for determining the optimum distribution of surface bonding as a function of the prosthesis material properties. Several different objective functions will be tested, including minimization of the stress differences between the intact femur and the femur with the endoprosthesis. Each optimization will be subject to various constraints, including upper limits on the maximum shear stress at the bone-prosthesis interface. Finally, a two-dimensional model will be developed to investigate the relationships between Coulomb friction and subsidence and micromotion.

#### **Publications Resulting from This Research**

None to date.

## **[70] Total Surgical Replacement of the Human Hip Joint**

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**Sponsor:** *National Institute of Arthritis and Musculoskeletal and Skin Diseases, National Institutes of Health*

**Purpose**—The purpose of this research is to compare ingrowth of bone into three types of porous coating and to determine the effect of the type of coating and the degree of coverage of the stem on the remodeling of bone in cementless hip arthroplasty (THA). The work is further concerned with bone remodeling and associated structural changes in the proximal femur subsequent to im-

plantation of porous-coated femoral components and revision of failed cemented THA.

The premise of bone ingrowth fixation is that the prosthesis will remain firmly anchored to the host bone indefinitely. Complications due to bone remodeling constitute one of the major long-term concerns. The location of the porous coating and the stiffness of the stem are two design parameters



likely to influence the mechanical environment and, hence, remodeling of the proximal femur.

**Methodology**—A canine revision model and a canine model of a gap at the interface between the host bone and the porous coating is used to provide insight into the process of bone ingrowth, the possibility of enhancing this process, and cortical bone remodeling following cementless revision THA.

**Progress/Results**—The effect of disodium etidronate (EHDP) on biomechanical and histologic characteristics of bone ingrowth in a porous material was studied. EHDP was administered to six dogs at a dose of 2 mg/kg/day for eight weeks. Porous titanium fiber composites were inserted into the proximal humeri and the left olecranons of all animals after the first four weeks of treatment. After a total of eight weeks, all animals were sacrificed, and the bone-porous implant interfacial shear strength was determined.

Mean shear strength of fixation for the EHDP-treated group was reduced by 76 percent compared to the control group. Bone ingrowth was mineralized in all of the control specimens. Mineralization of tissue ingrowth was inhibited in all specimens from the EHDP-treated animals.

A left total hip arthroplasty was performed in 40 dogs. Thirty of the dogs had a titanium-ally femoral prosthesis that had one of three types of commercially pure titanium porous material applied along the length of the anterior and posterior surfaces of the stem. The remaining 10 dogs had a femoral component that was circumferentially

coated with commercially pure titanium that was plasma flame-sprayed along the length of the stem. Ingrowth of bone into all three types of porous coating was observed, indicating secure fixation.

By six months, there was more ingrowth of bone and new medullary bone adjacent to the proximal and distal aspects of the stems compared with the middle level of the stems in all groups. In all groups, a proximal-to-distal gradient of loss of cortical bone was observed by six months. The magnitude of loss of bone was dependent on the extent rather than the type of porous coating.

**Future Plans/Implications**—Radiographic evidence of aseptic loosening has been reported to be as high as 40 percent in cemented revision of failed cemented THA. Cementless porous-coated prostheses are being used for revision arthroplasty, but it is not known if bone ingrowth actually occurs in this situation, nor are the long-term effects on bone remodeling known. Resorption of cortical bone carries the risk of mechanical failure of the bone or implant with formidable problems for reconstruction.

Data from this work suggest that restriction of the porous coatings would diminish the extent of cortical adaptive changes. Therefore, the extent of the porous-coating coverage of the femoral component is a critical consideration in the design for cementless total hip arthroplasty.

#### **Publications Resulting from This Research**

**Effect of Disodium Etidronate (EHDP) on Bone Ingrowth in a Porous Material.** Rivero DP, Skipor AK, Singh M, Urban RM, Galante JO, *Clin Orthop* 215:279-286, 1987.

### **[71] A Force Vector and Pressure-Sensing Endoprosthesis for the Human Hip**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The very high pressures measured during certain activities of daily living (ADL) which have been shown to be associated with significant muscular co-contraction across the hip joint have raised questions on the adequacy of current estimates of

the force vector at the human hip. Accordingly, a new design of femoral head replacement prosthesis has been completed and validated, which incorporates both 14 pressure transducers and a force vector and moment transducer.



The externally-powered, telemetry-electronic package in the pressure-sensing prosthesis which has operated flawlessly for over five years *in vivo* will be adapted by increasing channel capacity. In contrast, battery-powered designs, which have limited life and introduce hazardous material into the body, the induction-powering approach has unlimited life and no bio-incompatible material.

The adoption of an endoprosthesis, rather than using a total hip replacement design, insures that the natural geometry and kinematics of the hip joint are preserved, since the optimally-sized metal ball bears against the natural acetabulum. By contrast, total hip reconstruction changes the natural geometry of the joint.

**Implications**—The force vector measurements during ADL will quantify the extent of muscle agonist-antagonist co-contraction, and contribute to design

criteria for joint replacement prostheses. These same data acquired from surgery through recovery and rehabilitation will augment extant pressure data acquired thus far in influencing patient management and rehabilitation protocols following all kinds of major hip surgery. The concurrent acquisition of the force vector and the multiple pressure recordings will permit accurate reconstruction of the three-dimensional, temporal distribution of pressure in the hip joint during movement protocols, and thereby contribute to enhanced understanding of synovial joint biomechanics, lubrication, and tribology, and identify the possible role of mechanical factors in the etiology of osteoarthritis.

#### **Publications Resulting from This Research**

**In Vivo Measurement of the Joint Reactive Force in the Human Hip Joint.** Keita I, Masters thesis, Department of Mechanical Engineering, Massachusetts Institute of Technology, 1989.

### **[72] Patient Management and Rehabilitation Protocols Following Major Hip Surgery Based on Quantitative In Vivo Data**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research; VA Medical Center, Boston, MA*

**Purpose**—This project collects and interprets data from human subjects with femoral head replacement prostheses which quantify and telemeter the pressures experienced by acetabular cartilage, over the entire period from surgery, through recovery and rehabilitation, into the activities of daily living. Thus, for the first time objective data defines the mechanical environment of the hip during patient management and rehabilitation protocols.

All patients undergo post-surgical patient management and rehabilitation protocols. The appropriate ordering, optimum post-operative time for initiation, proper duration, and appropriate details of each protocol of these management and rehabilitation practices, are based on subjective generalizations derived from past experience with similar patients. Thus, protocols vital to the rapid, safe, and full recovery of the patient rest solely on qualitative observations. *De novo* quantitative objective data is not available to evaluate these traditional processes and consider alternatives.

**Methodology/Progress**—A pressure-instrumented prosthesis with 14 small pressure sensors integral with the spherical, metal, pseudo-femoral head measures the focal pressure experienced by acetabular cartilage as it articulates against the femoral component. The first unit was implanted in June 1984. Over a 5-year period, data was acquired during surgery, post-operative recovery, immobilization, mobilization while in bed, muscle exercise, all stages of ambulation and then during normal gait and over movement patterns, such as rising from chairs, stair-climbing, jumping, and jogging. During movement protocols, the pressure data was complemented with six-degree-of-freedom kinematic data from the body segments of the lower extremity and the pelvis and foot-floor force from dual forceplates. Very high local pressures measured during certain movements indicate significant muscle co-contraction, which has been confirmed from concurrent electromyographic data from the major muscle groups crossing the hip joint.



**Preliminary Results/Implications**—The pressures measured during the various stages of recovery and rehabilitation are of direct relevance to the evaluation of traditional rehabilitation procedures. Much of the data demonstrates inconsistencies with what has been presumed to be meritorious and commonly accepted rehabilitation practice, both in ordering and timing. To cite several examples, most present immobilization practices produce higher maximum pressures than does pedaling a stationary bicycle, a common early mobilization procedure. Muscle contraction exercises performed in bed, well before attempts at ambulation, produce pressures of the same magnitude as those during the stance phase of level walking measured a year post-operative. Virtually no correlation exists between the recorded maximum pressures and the current sequence in ambulation therapy. The maximum pressures measured during walking indicate no further rise after six months which correlated with the clinical observation of normal gait. The highest pressure measured to date was 18 MPa when rising from a normal (45 cm) chair. It is astounding that this high pressure is in the same range as that produced when a hydraulic jack lifts up a car.

This new quantitative pressure data can provide the basis for a more rational definition of appropriate protocols applied during recovery and rehabilitation following major hip surgery. The longitudinal data may explain why acetabular protrusion sometimes occurs following femoral head replacement. Fit of the prosthesis is critical, as is shown by our early *in vitro* studies. The new data

are also influencing surgical practice by indicating the directions of maximum pressure.

**Future Plans**—A second pressure-instrumented prosthesis, which incorporates a number of design improvements, was implanted during the fall of 1989. A more extensive series of implants will augment the pressure data, with direct measurement of the force vector across and moments about the hip.

#### Publications Resulting from This Research

**Arising from a Chair: The Role of Bi-Articular Muscles in Resolving Lombard's Paradox.** Catani F, Hodge WA, Mann RW, *Ninth Annual Conference of IEEE/EMBS*, Boston, MA, 1987.

**Hip Dynamics in Level Walking, Stair Climbing and Rising from a Chair.** Catani F, Hodge WA, Mann RW, *Winter Annual Meeting of the American Society of Mechanical Engineers*, Boston, MA, 1987.

**Automatic 6-D.O.F. Kinematic Trajectory Acquisition and Analysis.** Antonsson EK, Mann RW, *Trans ASME J Dyn Syst Meas Control* 111:31-39, 1989.

**Effects of Isokinetic and Isotonic Exercise on In Vivo Hip Contact Pressure.** Elbaum LE, Krebs DE, Riley PO, Carlson K, Catani F, Mann RW, Hodge WA, in *Transactions of the 35th Annual Meeting of the Orthopaedic Research Society*, 225, 1989.

**The Effects of Running and Gaining Weight in Comparison with Normal Gait on Pressures Measured in the Human Hip Joint.** Harris CL, Krebs DE, Riley PO, Carlson KL, Hodge WA, Mann RW, in *Proceedings of the 13th Annual Meeting of the American Society of Biomechanics*, Burlington, VT, 1989.

**Contact Pressures from an Instrumented Hip Endoprosthesis.** Hodge WA, Carlson KL, Fijan RS, Burgess RG, Riley PO, Harris WH, Mann RW, *J Bone Joint Surg* 71-A(9):1378-1386, 1989.

**In Vivo Hip Contact Pressures During Exercise and ADL.** Krebs DE, Elbaum LH, Riley PO, Catani F, Mann RW, Hodge WA, *Phys Ther* 69:384, 1989.

## C. Knee

### [73] Implant Fixation by Post Insertion Pressurization of Polymethylmethacrylate

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A143-2RA)

**Purpose**—The premise on which this project continued was that increased penetration of acrylic bone cement achieved by increased pressure in a closed

system would produce a stronger bone cement interface. A cannulated single-axis knee replacement and a system of seals and clamps was devised in



which the cement was injected through the prosthesis after it was placed, and the open end of tibia or femur sealed.

**Progress**—The prostheses were originally designed for canines, but when the local supply evaporated we had to obtain alternate animals for the *in vivo* studies. A breeder of pygmy Spanish goats was located. Preliminary experience with these animals (that weigh from 25 to 40 kilograms), demonstrated their utility.

A series of 12 goats, in which 24 cemented knee replacements were done, has been completed. One side was cemented by conventional hand-packing technique. On the contralateral side, the cement was pressurized at 100 psi. Preliminary evaluation showed cement penetration far greater when the cement was pressurized, than on the hand-packed side. In addition, there was severe cortical necrosis, exuberant periosteal new bone formation, and gross loosening at the bone cement interface. We are attributing this reaction to excessive penetration.

**Preliminary Results**—In an effort to utilize the benefits of pressure, and also limit the penetration of cement, we have reduced the amount of monomer used, thereby increasing the powder to liquid ratio (P/L) from the standard 2.0 to 2.7, which greatly increases the viscosity.

As determined in our lab, increasing the P/L ratio also increases the compressive strength 30 percent, increases the density from 1.13 for a 2:1 ratio to 1.16 (the density of plexiglass is 1.18), and reduces the peak exotherm 88 degrees Centigrade to 71 degrees (a reduction of 19 percent).

We have just completed a series of knee replacements in goats. High viscosity (2.7 P/L ratio) cement was used in one-half of this group, and conventional cement in the other half. Sacrifice was ten weeks postoperatively, at which time a time-zero procedure was done at the contralateral side.

Currently, evaluation by radiographic, biomechanical, and histological techniques is under way.

#### Publications Resulting from This Research

- Regional Variation in Shear Strength of the Bone-Polymethylmethacrylate Interface.** Bean DJ, Convery FR, Woo SLY, Leiber RL, *J Arthroplasty* 2(4):293-298, 1987.
- Sustained Pressurization of Polymethylmethacrylate: A Comparison of Low and Moderate Viscosity Bone Cements.** Bean DJ, Hollis JM, Woo SLY, Convery FR, *J Orthop Res* 6:580-584, 1988.
- Intramedullary Plugs in Cemented Hip Arthroplasty.** Beim GM, Lavernia C, Convery FR, *J Arthroplasty* 4(2):139-141, 1989.
- Cardiopulmonary Function During Canine Total Knee Replacement Using Sustained Pressurization of Bone Cement.** Weiner GM, Convery FR, Devine S, Reindel E, *J Arthroplasty*, accepted for publication.
- Acetabular Augmentation in Primary and Revision Total Hip Replacement with Cementless (Ingrowth) Prostheses.** Convery FR, Minter-Convery M, Meyers MH, *Clin Orthop*, accepted for publication.

### [74] Articular Cartilage Replacement Prostheses for the War Injured and Aging

**Myron Spector, PhD; Greg Brick, MD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A424-RA)

**Purpose**—The purpose of this investigation is to develop a prosthesis that can replace focal defects in articular cartilage. In its initial form, this prosthesis would be a cylindrical implant inserted into holes drilled through the articular cartilage defects. The device must have a polymer surface that can articulate against the opposing natural articular cartilage without causing accelerated degeneration of that tissue. The working hypothesis, based on

preliminary findings, is that a polymer with low surface energy (i.e., hydrophobic) will yield the most favorable performance when articulating against natural articular cartilage.

**Methodology**—Wear-test apparatus is to be constructed to screen candidate materials for their ability to articulate against natural articular cartilage without causing degeneration to the cartilage. Proto-



type devices with a compressive compliance comparable to natural cartilage will be constructed. Prototype devices will be implanted in dogs.

**Progress**—Construction of the apparatus to measure friction and wear of prototype materials against natural articular cartilage is being completed. A method to produce regularly varying surface energy through fluorination of polymer surfaces has been identified and specifications for specimens completed. Plans for the measurement of the compressive compliance of candidate specimens have been completed.

**Future Plans/Implications**—Fluorinated polymer surfaces with varying surface energy will be evaluated in the apparatus to assess the friction and wear produced when articulating against natural articular cartilage. An indentation test for compressive compliance will be employed in evaluation of candidate elastomeric materials and natural articular cartilage from several species, and from several sites in the knee joint of dogs. Surgical procedures implanting osteochondral allografts and autografts will be performed in dogs in order to yield control information.

#### **Publications Resulting from This Research**

None to date.

## **[75] All-Plastic Total Knee Replacement**

**Myron Spector, PhD; Greg Brick, MD; E.J. Cheal**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A217-2RA)*

**Purpose**—The overall objective of this project is to develop a total knee replacement (TKR) prosthesis made entirely from polymeric materials. The hypothesis to be tested is that a carbon-fiber reinforced polymeric femoral component serving as a “flexible condylar resurfacing prosthesis” (FCRP) will allow for maintenance of near-normal stresses in the underlying bone, and thus prevent the osteopenic condition that develops under stiffer metallic femoral components because of “stress shielding.” A second potential advantage of an all-plastic TKR is the improved tribological performance (i.e., reduced wear).

**Methodology**—Carbon-fiber (continuous fibers) reinforced polysulfone (C/PSF) and the polyetheretherketone (C/PEEK) will be investigated as the materials of fabrication for the FCRP. Surface treatment methods will be employed to alter the surface energy of the polymer films serving as the articulating surface of the device. Apparatus will be constructed to evaluate the wear (and friction) produced as polymers and composites articulated against service surfaces of the same type and polyethylene.

A second apparatus will be employed to determine the particle size distribution and morphology

of wear debris produced as various polymers and composites are abraded against bone. The mechanical properties of the composite materials will be characterized, and testing performed to provide data for the validation of finite element models. A histological “screen” of the local tissue response to C/PEEK will be assessed by implanting disk-like specimens subcutaneously in rabbits and by injecting particles into the knee joints of the animals.

*In vivo* evaluation of the bone remodeling around composite femoral components will be performed in dogs. Cobalt-chromium alloy components will serve as implant controls, and the unoperated knee the anatomical control. A finite element analysis of composite and metallic femoral components in a canine knee will be performed. The computer models will allow for the assessment of the influence of design modifications on the stress distribution. The results of the finite element models will be correlated with the histology observed around the canine prostheses.

**Progress**—Achievements in the previous project period have been the construction of two wear-test apparatuses. One has been designed to evaluate the friction and wear of polymer-on-polymer articula-



tions. A second apparatus has been constructed to determine the morphology and particle size distribution of wear debris generated from polymer bearings against bone (as could occur with noncemented, "press-fit" TKR). In this previous project period, TKR was performed in a canine model. Radiographic evaluation of bone modeling around conventional TKR prostheses in human subjects was performed to provide the rationale for all-plastic TKR.

**Results**—A retrospective radiographic review of current TKR prosthesis was carried out to assess alterations in bone density under conventional rigid metallic components. Osteopenia was found under the femoral condyles in up to 78 percent of the cemented and noncemented components. In an associated laboratory test, a conventional metallic femoral component was implanted in a cadaver femur. The objective was to determine the amount of bone loss required before radiolucency could be distinguished on a lateral radiograph. The results of this experiment revealed that at least 15 percent bone mineral needs to be lost before radiolucency becomes evident in a radiograph. We estimate that the nature of radiolucency we find under metallic femoral components in retrospective clinical follow-up might correspond to a loss of about 30 percent bone mineral. Previous studies suggest that a loss of this much mineral would lead to a reduction in bone strength of more than one-half. The finding of radiolucency under metallic femoral

condyles provides the rationale for investigating more flexible femoral components because this osteopenia condition is probably the result of "stress shielding" under rigid metallic components.

Two all-plastic TKR prostheses machined from a fiber-reinforced polymeric material were implanted into two dogs. Control prostheses with cobalt-chromium alloy femoral components articulating with polyethylene tibial plateaus were also implanted into two animals. All of the devices were implanted as press-fit prostheses (i.e., noncemented). Postoperative gait analysis employing a force plate revealed that the animals were applying loads to the operated limbs. Postmortem histological evaluation revealed that the particular polymer employed in these preliminary studies elicited an unfavorable inflammatory response, and underwent excessive wear. It was for this reason that other polymers (PSF and PEEK) will be employed in future experimentations.

**Future Plans/Implications**—The wear-test apparatus will be completed to allow for the reliable and precise measurement of the coefficient of friction and wear of candidate polymeric devices. Candidate materials will also be screened in a biocompatibility test, and undergo mechanical testing. Finite element modeling of the all-plastic TKR prosthesis will begin.

#### **Publications Resulting from This Research**

None to date.

### **[76] Fixation of Experimental Osteotomies of the Human Patella with Biodegradable Material versus Tension Wire a.m. AO**

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Gentofte Hospital, 29000 Hellerup, University of Copenhagen, Denmark

**Sponsor:** *Biodegradable Research Laboratory, Glostrup, Denmark*

**Purpose**—The intention was to study the initial tensile strength of patella-osteotomies fixed with biodegradable polyglycolic acid (PGA) rods.

**Progress/Methodology**—Experimental osteotomies on 12 pairs of human cadaver patellae were fixed with two crossing PGA-rods on one side, and tension wire a.m. AO on the other side. The

implanted PGA-rods had a diameter of 2.0 mm and a length of 50 mm. The rods are composed of self-reinforced, composite polyglycolic acids. PGA is metabolized via tricarboxylic acid cycle and gradually eliminated from the body as water and carbon dioxide within approximately 3 to 4 months. Dual photon absorptiometry was applied on all specimens and bone mineral content (BMC) and



bone mass density (BMD) were recorded. The tensile strength was tested in an Instron Universal Test machine.

**Preliminary Results**—The median tensile strength until start of dislocation was 48 N (range 0-75) for the AO method, and 70 N (range 20-125) for the PGA method ( $p < 0.01$ ). The median tensile strength until dislocation gap of 1 mm was 120 N (range 45-250) for the AO method, and 123 N (range 60-385) for the PGA method ( $p > 0.1$ ). We found no correlation between the tensile strengths and the BMC and BMD.

**Future Plans**—The present study indicates that the initial tensile strength of patella-osteotomies fixed with biodegradable PGA was comparable with that of tension wire a.m. AO. We intend to perform measurements *in vivo*, including monitoring both tensile strength and flexural strength.

#### Publications Resulting from This Research

**Fixation of Experimental Osteotomies of the Human Patella with Biodegradable Material versus Tension Wire a.m. AO.**  
Lyndrup P, Andersen S, Sandberg Sorensen T, Albrecht-Olsen P, *Acta Orthop Scand* (in press).

## D. Spinal

### [77] Development and Testing of New Spinal Implant Systems

**Richard J. Nasca, MD; Jack E. Lemons, PhD**  
VA Medical Center, Birmingham, AL 35233

**Sponsor:** VA Rehabilitation Research and Development Service (Project #B365-2RA)

**Purpose**—The overall objective of this program is to develop basic biomechanical cyclic fatigue data on fresh animal swine spines, standard surgical reconstructive systems, and new anterior and posterior surgical implant devices. The associated information will be used to provide a basis for the design and testing of safer and more biomechanically stable devices.

**Progress**—With the completion of the cyclic axial and torsional characterizations of the standard Harrington, Luque and Drummond implant systems, using fixed deformation limits, the studies were extended to a prototype anterior device, early design for a new posterior system, and improvements in dynamic testing methodologies for rapid on-line computer based data acquisition.

An anterior implant has been designed and three prototypes have been evaluated by cyclic testing *in vitro*. The current prototype has been tested in four swine spines. Three of the four tests extended to 100,000 cycles in axial compression and torsion at 1 to 2 Hz using fixed applied forces and deformation limits. One spine fractured at 1120

cycles at the level of the anterior implant insertion. Radiographs taken on the other spines at insertion, during, and after implant testing did not show any untoward changes in the implant or adjacent vertebral bodies.

The implants were stable through testing and did not dislodge. In one spine, the upper prong of the device was not well-seated at insertion but did not displace during cyclic testing to 100,000 cycles. Removal of a vertical portion of bone above and below the disc space and careful preparation of the anchor sites was found to be critical to implant stability. Orders have been placed for down-sized porous-coated titanium alloy implants in preparation for extended *in vitro* and *in vivo* testing in primates.

We are presently designing a posterior intersegmental implant system. Anatomical measurements of human cadaver spine lumbosacral facet-pedicle dimensions have been completed. It appears feasible to base the anchoring post of the posterior implant on the pedicle-facet complex. We plan to design a press-fit porous ingrowth cylindrical anchor to be inserted in the pedicle-facet for fixation into

the spine. Each pedicle-facet anchor will be subsequently attached to a graphite fiber reinforced composite rod. The paired rods will be cross-linked. An open attachment connector for easy insertion of the contoured rods will allow for preservation of physiologic curves and maximal correction of deformities.

During the last year, we developed a software program and method for assessing dynamic motion profiles during cyclic testing using the new Peak-Performance System. This involved two video cameras, a digitizing unit, and a modified computer program. The Peak-Performance unit purchased in March 1989 has been utilized to generate two-dimensional linear angular displacement analyses, thereby eliminating the hand digitization of still photographs. We believe this type of data acquisition is a major breakthrough in analyzing cyclic-motion profiles.

**Future Plans**—The recent delivery of a Bionix M.T.S. spine testing machine should enable us to provide further quantitative biomechanical data relative to cyclic testing of the proposed implants.

We continue to believe that cyclic testing of the proposed anterior and posterior implant systems combined with *in vivo* evaluation in primates will ultimately result in the development of safer and more biomechanically stable spinal implants. These implants will be valuable adjuncts in the treatment of veterans with spinal injuries, degenerative disc disease, and spinal deformities.

#### **Publications Resulting from This Research**

**Multiaxis Cyclic Biomechanical Testing of Harrington, Luque, and Drummond Implants.** Nasca RJ, Lemons JE, Walker J, Batson S, *Spine* (accepted for publication).



# IV. Spinal Cord Injury

*For additional information on topics related to this category see the following Progress Reports: [44], [46], [51], [164], [176], [230], [232], [258], [326], [328], [329], [330], [331], [384].*

## A. General

### [78] Acceleration Monitoring of Acute Spinal Injury Patients: A Pilot Study

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**Sponsor:** *VA Rehabilitation Research and Development Service (Pilot Project #B967-PA)*

**Purpose**—To meet the need for more precise methods of quantifying the dynamic performance of devices for immobilizing, moving, and maintaining traction on cervical spinal cord injury patients, a pilot project was initiated to measure relative head-to-trunk motion using accelerometric sensors.

**Methodology**—Measurements were made using 3-axis, 5-g accelerometers; a cable tension transducer was inserted into a traction-generating apparatus. Following calibration of sensors, investigators placed accelerometers secured by Velcro bands on the forehead and chest. Sensors were connected via cables to an amplifier package feeding into an IBM PC/AT with an analog/digital converter. Measurement runs were 120 seconds in duration and were continuously videotaped against a 10-cm grid backdrop. An audio time mark on the tape was synchronized with the digital recordings and later displayed by the computer to identify known events with changes in acceleration.

Measurements were begun with the subject supine; the head and neck were in neutral position. Neck orthoses were installed with the subject supine. The subject was logrolled 60 to 90 degrees to the right, left, returned to the supine position, and raised to the sitting position. The sequence next involved active (volitional muscle action) and pas-

sive (externally applied) neck flexion, extension, right and left lateral bend and rotation, compression, and distraction. We define X-axis accelerations as those which subject the neck to compression or distraction forces; the Y axis corresponds to lateral displacement, and the Z axis to flexion and extension.

New prehospital support devices that were evaluated include: the traction, alignment, cervical immobilization, and transport (TACIT) device (a short spine board with width-adjustable foam-padded shells for applying non-invasive traction); the Miller backboard; the Dixie backboard; and the Rehabilitation Research and Development Center's composite backboard.

Three types of rigid cervical collars—Philadelphia, Malibu, and StifNeck—were evaluated using normal volunteers. Manual and automatic operation of the RotoRest kinetic bed, as well as lifting onto this bed, were tested at Santa Clara Valley Medical Center, using normal volunteers and post-acute SCI patients.

**Results/Implications**—This pilot study demonstrated only how the devices might be evaluated under dynamically realistic conditions of use, in order to identify specific times or activities which create higher-than-background accelerations and

therefore higher risk of unintentional neck displacement.

Examples of high-risk events common to several devices are: 1) closure of fasteners during installation; 2) contact of backboard edges with the floor; and, 3) lateral head motion due to poor fit, loose forehead and chin straps, and nonrigid attachment of a restraint to a backboard. Other sources of acceleration peaks are: 1) slipping of the subject's torso, or, less frequently, legs, if straps have not been adequately tightened; 2) jostling of one end as the attendant's hands grasp the board; 3) progressive loosening of the Velcro attaching the Miller head restraint to the edge of the board; and, 4) dropping the end of the board when the attendant's hands are released at the end of the cycle.

**Future Plans**—Further research will concentrate on investigation of factors contributing to high-risk

events identified during earlier tests. Experimental work will be confined to repetition of the patient-handling activities which produce such events, rather than the survey-type sequences presently performed. Suggestions for changes in procedures to reduce risk of unintentional head-to-body motion will be proposed to medical staff and to equipment manufacturers; if incorporated, retests will be performed to ascertain whether relative motion is actually reduced. Also, use of accelerometry for routine monitoring of head-to-body motion will be demonstrated, and feedback from nursing staff, therapists, and physicians will be obtained as to its feasibility.

#### **Publications Resulting from This Research**

None reported.

### **[79] Factors Influencing Joint Compliance and Reflex Mechanisms Following Spinal Cord Injury**

**Charles Robinson, DSc, PE; Gyan Agarwal, PhD; Gerald Gottlieb, PhD; Bryan Flaherty, MS; Robert Kogel, RPT; Ron Cramer**

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Rush-Presbyterian-St. Luke's Medical Center, Department of Physiology, Chicago, IL 60612

**Sponsor:** VA Rehabilitation Research and Development Service, (Project #B446-RA)

**Purpose**—The purpose of this study is to investigate the influence that electrical muscle stimulation (EMS) and various routinely used anti-spasmodic pharmaceuticals have on the compliance (or conversely stiffness) of the ankle joint and on the reflex circuitry about that joint for individuals with spinal cord injury.

**Progress**—We have begun a series of investigations to fulfill our purpose and we are in the process of extending these observations to the knee joint. Our laboratory built a custom, computer-controlled, ankleplate/torque motor system of extremely low inertia, instrumented with commercial sensors to measure torque, displacement, and acceleration. Four channels of differential EMG recording are also available. All signals are captured into an IBM-compatible computer, via 8 channels of a

12-bit A/D converter, and all signals are simultaneously recorded in analog form on a 14-channel computer-controlled VHS tape deck. Another eight channels of the A/D converter are available to input to the computer the data stored on these VHS cassettes.

All programming is done in ASYST, a laboratory computer language that permits near-real-time display of torque, displacement, acceleration, and EMG signals on the computer monitor. A digital scope is available to monitor any two signals on-line and is also under computer control. ASYST allows the choice of stimulus paradigm (sine wave, ramp, step) and all stimulus values (frequency, amplitude, resistance, etc.). Post-processing of signals yields a hard copy plot of all relevant data aligned by trials of similar nature. Our laboratory also has an integrated muscle stimulator/EMG recorder (2 chan-



nels) with artifact suppression. This gives us a unique resource to measure joint compliance and reflex activity during EMS.

We have built a platform similar to that used by Dr. Roger Glaser at Wright State University for progressive quadriceps exercise using electrical muscle stimulators on individuals with spinal cord injury while they remain seated in their own wheelchairs. We have added the capability to do progressively loaded ankle dorsi- and plantar-flexion exercises via EMS. The exercise stimulators ramp up the current from a threshold level to a maximum of 150 mA, with the ramp reversing at a current level where a specified extension or flexion angle is reached or when signaled by the subject or the computer.

**Preliminary Results**—We have begun patient accrual into our protocol. Results with our initial subjects indicate that our test fixture indeed provides reliable and repeatable results. We have now begun to measure the effects of titrating the doses of

antispasmodic medications (like valium and baclophen) already prescribed for our subjects, and the effects of EMS on joint compliance and neural reflex activity. Careful attention is being paid to the potential effects of latent descending spinal cord pathways in individuals with spinal cord injuries.

#### **Publications Resulting from This Research**

**Spasticity in Spinal Cord Injured Patients: 1. Short Term Effects of Surface Electrical Stimulation.** Robinson CJ, Kett NA, Bolam JM, *Arch Phys Med Rehabil* 69:598-604, 1988.

**Spasticity in Spinal Cord Injured Patients: 2. Initial Measures and Long Term Effects of Surface Electrical Stimulation.** Robinson CJ, Kett NA, Bolam JM, *Arch Phys Med Rehabil* 69:862-868, 1988.

**Strength and Endurance Changes Following Electrical Stimulation of Muscles Paralyzed by Spinal Cord Injury.** Robinson CJ, Kett NA, Bolam J, in *Proceedings, ICAART 88*, Montreal, 322, 1988.

**Considerations for a Clinical FNS Training Program in Spinal Cord Injury: Influence of Surface Electrical Stimulation on Muscle Strength, Endurance, Spasticity, Cross-Sectional Area and X-Ray Density; and on Urodynamic and Psychological Factors.** Robinson CJ, *Engineering Foundation's Neuroprosthesis Conference*, Potosi, MO, 1988.

## **[80] The Corticospinal System**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B389-RA)

**Purpose**—The purpose of our studies is to identify corticospinal systems which may be important in the recovery of function following spinal cord and/or cortical injuries.

**Progress**—We have recently presented evidence that the medial wall of the hemisphere in macaques contains three premotor areas which are somatotopically organized. In addition, we have shown that each premotor area projects directly to the spinal cord. One of these premotor areas is the supplementary motor area (SMA) in a medial portion of area 6. The second is caudal cingulate motor area (CMAc), which is located in portions of areas 6 and 23c on the dorsal and ventral banks of the cingulate sulcus. The third premotor area is the rostral cingulate motor area which lies more rostrally in the cingulate sulcus in area 24c. Our recent studies in monkeys have examined the somatotopic organization of these premotor areas

more directly, using double labeling techniques. In the same animal, one fluorescent tracer was injected into lower cervical segments, and a second fluorescent tracer was injected into lower lumbar segments of the spinal cord.

**Results**—We have found that the regions of each premotor area which project to lower cervical segments do not overlap substantially with the regions that project to lower lumbar segments. In fact, the overlap observed in the premotor areas was comparable to what is seen in the primary motor cortex of the same animals. The regions of overlap where neurons projecting to lower cervical and lower lumbar segments were intermingled contained only a small number of double labeled neurons.

**Future Plans/Implications**—These results support the concept that the premotor areas on the medial wall of the hemisphere contain distinct arm and leg



representations. At the present level of analysis, the premotor areas appear to be as somatotopically organized as the primary motor cortex. These observations have some important implications for promoting and sustaining recovery of motor function following damage to the primary motor cortex. The present results indicate that multiple somatotopically organized premotor areas exist on the medial wall of the hemisphere. Furthermore, our studies have shown that each of these areas has substantial projections to the spinal cord. Future experiments will determine the pattern of spinal cord termination of efferents from each of the premotor areas. Thus, we will examine whether each premotor area has the potential to control the output of motoneurons directly.

### [81] Pilot Study of Autologous Frozen Blood in Spinal Cord Injured Patients

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Sponsor: Eastern Paralyzed Veterans Association

**Purpose**—To develop an autologous blood program with the purpose of: 1) evaluating the logistics of initiating and using such a program; and, 2) examining outcome criteria which compare adverse transfusion effects in recipients of autologous frozen blood versus community blood units.

In recent years there has been an increased risk of transfusion-transmitted diseases such as Non-A, Non-B (NANB) hepatitis, cytomegalovirus, human T-lymphotrophic virus (HTLV-I), and human immunodeficiency virus (HIV), as well as alloimmunization reaction disorders. This, coupled with the fact that spinal cord injured individuals often need surgery at some time in their future, makes the concept of autologous blood storage very attractive.

**Methodology**—After obtaining informed consent, subjects will be screened using conventional donor-room criteria. In addition, specific and surrogate markers of transfusion-transmitted viral disease and alloimmunization will be evaluated to obtain baseline data. Blood units will be fractionated into packed red blood cells and plasma, the red cells will

### Publications Resulting from This Research

**Anatomical Organization of Multiple Motor Areas in the Frontal Lobe: Implications for Recovery of Function.** Strick PL, in *Advances in Neurology*, Vol. 47, S.G. Waxman (Ed.), New York: Raven Press, 293-312, 1988.

**Corticospinal Projections from the Medial Wall of the Hemisphere.** Hutchins KD, Martino AM, Strick PL, *Exp Brain Res* 71:667-672, 1988.

**Origin and Density of Corticospinal (CST) Projections from the Premotor Areas of Macaques.** Dum RP, Strick PL, *Soc Neurosci Abs* 14:821, 1988.

**Premotor Areas on the Medial Wall of the Hemisphere: Corticospinal Projections to the Cervical and Lumbosacral Cord.** He SQ, Dum RP, Strick PL, *Soc Neurosci Abs* 15:282, 1989.

**Cortical Projections from the Motor Areas in the Frontal Lobe.** Dum RP, Strick PL, in *International Symposium on Brain Sciences*, Japanese Scientific Societies Press (in press).

be glycerolized, and both products will be frozen to provide both red cells and fresh-frozen plasma for later autologous use.

A PC will be used to identify each patient enrolled in the study through a File Manager-based program which interfaces with the routine Blood Bank recipient identification system. This should be activated with each routine blood request to protect against inadvertent homologous transfusion of patients who have autologous blood stored.

When blood is requested for subjects in this study, the treating physician will be informed of the availability of autologous blood units. Every effort will be made to limit the extent of transfusion to the amount of autologous blood stored.

Each patient receiving products prepared for this study will be matched as closely as possible with a control patient receiving homologous blood. The control patient for each autologous blood recipient will be sought once the subject is transfused, and will be evaluated for baseline markers of transfusion-transmitted viral disease.

The viral markers to be evaluated will be four standard tests. These are: 1) hepatitis B surface



antigen; 2) hepatitis B core antibody; 3) alanine aminotransferase; and, 4) anti-human immunodeficiency virus antibody. Assays of each of these four markers will be repeated in both study subjects and controls at post-transfusion intervals appropriate to their development of titer. (Autologous blood stored frozen using appropriate cryopreservative

methods is useful for years. Current FDA policy allows storage using some methods of up to five years, and this may soon be extended to twenty years.)

#### **Publications Resulting from This Research**

None reported.

## **[82] Psychosocial Adjustment of Persons with Combined Spinal Cord Injury and Traumatic Brain Injury: A Longitudinal Investigation**

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**J.S. Richards, PhD**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Spinal cord injury (SCI) is often the result of a rapid deceleration event and/or a direct impact to the head, neck, or trunk. Therefore, in some cases, an associated traumatic brain injury (TBI) is sustained in addition to the SCI. While evidence of a concomitant traumatic brain injury is at times quite apparent, at other times “softer” signs of a TBI may not be so apparent and may be overlooked. This project is an attempt to determine whether persons with concomitant TBI in addition to SCI: 1) experience more marital/familial distress post-discharge than a matched group of patients with SCI only; 2) achieve less progress educationally and/or vocationally post-discharge than a matched group of patients with SCI only; 3) experience more psychological/behavioral distress post-discharge than a matched group of patients with SCI only; and, 4) experience more social maladjustment post-discharge than a matched group of patients with SCI only.

**Methodology**—The social, vocational, psychologi-

cal, and familial adjustment over time, of a cohort of persons with SCI and concomitant TBI, and a matched control group of persons with SCI only, have been compared through a battery of well validated psychometric measures administered via mail.

**Preliminary Results**—We have identified the SCI/TBI cohort and matched SCI-only controls. Twenty-one subjects were matched on length of time post-injury, neurologic level and extent of lesion, sex, race, and years of education.

Some differences have been found between the SCI/TBI and SCI-only groups on several of the measures studied. On average, study subjects were 3 to 4 years post-injury.

**Future Plans**—Study results are being prepared for conference presentation and journal submissions.

#### **Publications Resulting from This Research**

None reported.

## **[83] Fundamental Studies in Spinal Cord Injury**

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**Phanor L. Perot, Jr.**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—In order to provide a scientific basis for possible therapeutic approach to human spinal cord injury, animal (rat) trials with multiple classifica-

tions of agents will be continued, including calcium entry blockers, steroids, hyperbaric oxygen, and antioxidants. In addition, therapeutic trials with

phosphate and other buffers will continue. Therapeutic trials will, at the same time, test various hypotheses concerning primary and secondary injury factors in the production of necrosis following traumatic injury. These include calcium toxicity, ischemia, and free radical injury. Lactic acid myelopathy *in vivo* developed during the last grant period will be evaluated to determine the extracellular pHs in the spinal cord required to produce myelopathic changes using pH electrodes and a chemical microsensor.

Studies will be completed on secondary changes in the rat spinal cord following Wallerian degenera-

tion and postmortem autolysis which are being compared with the primary traumatic events and are critical to the interpretation of the latter.

**Future Plans**—Future studies are anticipated that will determine the role of calcium in these secondary events present in the traumatized spinal cord. In addition, freeze-fracture membrane pathological evaluation of spinal cord trauma will be initiated.

#### **Publications Resulting from This Research**

None reported.

### **[84] Spinal Somesthetic Pathways**

**Charles J. Vierck, Jr.**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—The proposed studies have three major goals: 1) the improvement of neurological diagnosis of spinal cord injury by defining the sensory capacities that depend critically upon transmission along the dorsal spinal columns. This major somatosensory pathway has been investigated thoroughly by anatomical and physiological techniques, but psychophysical investigations are needed to determine the functional significance of organizational features that have been described; 2) focus analysis on the non-hairy (glabrous) skin of primates that is specialized for exquisite tactile sensitivity. The mechanical factors that determine the sensitivities of cutaneous receptors can be described by the application of video analysis techniques to microscopic views of the skin during indentation; and, 3) the introduction of pharmacological compounds directly on the spinal cord (intrathecally) in order to improve understanding of the participation of spinal cord circuitries in the control of pain, and the thorough evaluation of sensory and motor capaci-

ties. By comparing the effectiveness of a variety of opiate agonists in modulating pain reactions without producing other effects, improved methods of pain therapy can be suggested.

The proposed studies will be conducted with monkeys because the spinal pathways are quite similar among primates but differ considerably between primates and other mammals. The stimuli utilized in these studies are brief, non-injurious, and easily tolerated by monkeys and humans.

This is a multidisciplinary approach within the neurosciences, involving direct correlations of anatomical and physiological data with highly quantitative evaluations of sensory thresholds and motor reactions to precisely controlled somatosensory stimuli.

#### **Publications Resulting from This Research**

None reported.



## B. Medical Treatment

### [85] Compression and Ischemia as it Affects Spinal Cord Injury

**Steven R. Garfin, MD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B535-RA)

**Purpose**—Our spinal cord injury research will increase knowledge about the pathophysiology of spinal cord and spinal nerve root injury related to compression and ischemia. We will determine the critical limits at which acute compression alters intraneural and spinal cord blood flow, electrophysiologic function, nerve and spinal cord structure, and vascular permeability. Separately, we will study the effects of vascular occlusion to the spinal cord and cauda equina in terms of electrophysiologic function and histologic alterations. In both components of this study, reversibility and recoverability of the spinal cord function will be assessed.

The data will provide better understanding of the underlying causes of spinal cord and spinal nerve root injuries and suggest parameters on the effects of the duration and magnitude of compression, and ischemia tolerated in terms of the possibility of obtaining functional recovery. This information should be of use in helping design and develop

clinical tools to assess and treat spinal cord injuries.

**Methodology**—Our aims will be accomplished by the following groups of experiments: 1) investigations on the reaction of the spinal cord and spinal nerve roots to control the compression in terms of changes in structure electrophysiology (function), intraneural blood flow, and vascular permeability. These studies will delineate the role of mechanical factors in the development of the changes listed; 2) investigations on the reaction of spinal cord and spinal nerve roots to vascular ischemia (hypotension and hypoxemia) in terms of structural, vascular, and electrophysiologic (functional) changes; and, 3) determination of duration and magnitude of compression and vascular ischemia which lead to irreversible functional and structural changes in the spinal cord and spinal nerve roots.

#### **Publications Resulting from This Research**

None reported.

### [86] Transurethral Balloon Dilatation for Prostatic Obstruction

**Joseph E. Binard, MD; L. Baert, MD; K.U. Leuven; P. Werbrouck, MD**

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Department of Urology, University Hospital, St. Pieter, Belgium

**Sponsor:** Eastern Paralyzed Veterans Association

**Purpose**—Our purpose is to evaluate the optimal method for balloon dilatation in the treatment of prostatic obstruction and to determine the optimal indications. While balloon dilatation is compared with transurethral incision of the prostate in a randomized trial in Washington, DC, the changes that occur in the prostatic tissue during and after balloon dilatation will be studied in Leuven, Belgium. Data and results on the extent and duration of

dilatation that can relieve prostatic obstruction, and the effect of tissue damage in relation to extent and duration of dilatation will be exchanged.

**Methodology**—The relief of obstruction will be executed by the following clinical, dynamical, and radiological means: 1) patient questionnaire both pre- and post-treatment; 2) prostatic weight with transrectal ultrasonography and rectal examination;

3) cystoscopy; 4) intravenous urography; 5) uroflowmetry, pressure-flow studies and cystometry; 6) urethral pressure profile; 7) postvoid residual urine volume; and, 8) urethral caliber with transrectal sagittal ultrasonography and/or voiding cysto-urethrography.

The effect of tissue damage will be evaluated by physiological parameters in addition to common methods: 1) magnetic resonance imaging and/or transrectal ultrasonography of prostatic tissue pre/post balloon dilatation; 2) monitoring tissue oxygen tension and PH during/after dilatation; 3) monitoring tissue pressure during/after dilatation; and, 4) monitoring serum levels of prostate specific antigen (PSA) and prostatic acid phosphates pre/post dilatation.

The factor of prostate size upon treatment success will be considered, with the Leuven facility

considering subjects with prostates over 25 gm. These will be excluded from the Washington, DC, facility. However, they will use subjects with prostatic carcinoma, while Leuven will exclude these subjects.

**Progress/Implications**—The physical facilities necessary for the study are being put into place and coordinated. We hope the knowledge gained through this study in the application of balloon dilatation in the area of sphincter dysfunction will provide a means of performing a "bloodless" external sphincterotomy.

#### **Publications Resulting from This Research**

None reported.

### **[87] Escherichia Coli Urinary Infection: Molecular and Animal Studies on the Complement Resistance Mediated by Plasmid ColV**

**Felipe Cabello, MD**

New York Medical College, Valhalla, NY 10595

**Sponsor:** Eastern Paralyzed Veterans Association

**Purpose**—Urinary infections are a frequent cause of morbidity among the spinal cord injured population. The work of others and that of this investigator have demonstrated that *E. coli* isolated from urinary tract infections harbors the ColV plasmid with a high frequency.

Molecular and genetic studies have allowed us to identify two ColV genes: *iss* and *traT*, and their products, which are able to mediate resistance to serum antibodies and phagocytosis. This increases the virulence to invade tissues and produce infections such as urinary infections.

This study will focus on the molecular interactions between isogenic strains of *E. coli* differing in their expression of the *iss* and *traT* proteins on their surface with total human serum, human serum deficient in specific complement proteins, and isolated complement proteins. Urinary tract virulence of *E. coli* will be studied using a model containing serum-resistant genes.

These experiments will generate information to help understand the mechanisms of plasmid-encoded

serum resistance, and their relevance to the ability of *E. coli* to produce urinary infections. This is relevant to improved means for prevention, diagnosis, and treatment of urinary infections.

**Progress**—Experimental findings led to the investigation of the presence of virulence properties among ColV plasmids isolated from intestinal and extraintestinal *E. coli*. This was done using colony and Southern hybridization with DNA probes containing virulent DNA sequences.

The virulence properties investigated were the complement and phagocytosis resistance genes *traT* and *iss*, and the iron uptake genes *iuc* and *iut*, responsible for the synthesis of aerobactin and its outer membrane receptor. We also used some of the molecular reagents of this project in the analysis of the iron transport systems in *Salmonella typhi*.

**Future Plans**—Our future plans are outlined as follows: Molecular interactions between *TraT*+ cells and complement: 1) the effect of antibody on the



deposition of C9 on the surface of *TraT+* and *TraT-E.coli*; 2) the analysis of the role of C5b-7 and C5b-8 in complement resistance; 3) the role of C9 in cell lysis; and, 4) the role of C3 in phagocytosis.

Experimental urinary infection and role of ColV encoded properties: 1) strains; and, 2) animal experiments.

Epidemiology of ColV virulence properties: 1) studies on ColV; and, 2) studies on *S. typhi*.

#### **Publications Resulting from This Research**

None reported.

### **[88] Effects of Guanabenz on Bladder Function After Spinal Cord Injury**

**Jose R. Sotolongo, Jr, MD; John J. Tomasula, PhD; N. Eric Naftchi, PhD**  
VA Medical Center, Spinal Cord Injury Service, Bronx, NY 10468; Mount Sinai School of Medicine, Department of Urology, New York, NY 10029; New York University School of Medicine, Biochemistry Pharmacology, New York, NY 10016

**Sponsor:** *Eastern Paralyzed Veterans Association*

**Purpose**—Our purpose is to study the effect of guanabenz, an alpha-2 adrenoreceptor agonist, on urinary bladder function and neurological recovery in cats. The cats were subjected to a 400 gm-cm contusion injury of the thoracic spinal cord. Eight cats were treated with 1.3 mg/kg of guanabenz three hours after injury, and twice daily for eight weeks. Four injured cats were used as controls (untreated) and 12 intact cats were used as normal controls. Cystometrograms were used to measure bladder function in all the animals studied.

**Progress**—It has been shown that a 400 gm/cm impact to the cat spinal cord produces an irreversible lesion, and treatment with an alpha-2 agonist can improve the neurological and urological function in these animals. It appears that intraperitoneal treatment of spinal cats with guanabenz (Substance B, an alpha-2 agonist) has an ameliorative effect on

functional reorganization of the central spinal pathways modulating spasticity, micturition and lower limb function. The next part of the study involves guanphyline (Substance C). Cortical somatosensory potentials during urinary bladder function tests (urodynamics) were monitored on the spinal cats. The study is continuing to examine if there is a relationship between the presence of a cortical somatosensory response and the absence of dyssynergia, a trend observed during a preliminary study.

#### **Publications Resulting from This Research**

**The Effects of Alpha-2 Agonists on Spinal Rats and Cats.** Naftchi NE, Sleis JA, Tomasula JJ, Sotolongo JR (Abstract), *Trans Am Soc Neurochem* 1(19):160, 1988.

**Cortical Somatosensory Potentials Evoked by Bladder Distension in Spinal Cord Injured Individuals.** Sotolongo JR, Tomasula JJ, Marks P (Abstract), *Ann Neurol* 24(1):172, 1988.

### **[89] Mechanisms Underlying the Recovery of Sacral Autonomic Reflexes Following Spinal Cord Injury**

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**Sponsor:** *National Science Foundation*

**Purpose**—Studies have been conducted with animals to analyze the mechanisms underlying the recovery of the lower urinary tract function following injury to the spinal cord. Changes in the activity of the

lower urinary tract in paraplegic patients are to some extent similar to those occurring in patients with urethral obstruction induced by benign prostatic hypertrophy (e.g., both types of patients

have bladder instability and hyperreflexia). We have hypothesized that these changes are produced by facilitation of spinal reflex mechanisms. A series of electrophysiological and neuroanatomical experiments in cats and rats have confirmed this speculation and also revealed morphological changes in afferent pathways from the urinary bladder that might contribute to the reflex changes.

**Methodology/Results—Paraplegic cats.** In chronic spinal cats, involuntary micturition and bladder hyperreflexia are mediated by a spinal pathway triggered by C-fiber afferents in the pelvic nerve, whereas micturition in normal cats is mediated by a supraspinal reflex pathway initiated by A-fiber afferents. Capsaicin, a neurotoxin that acts relatively selectively on C-fiber and small myelinated fiber afferents, blocked micturition in spinal but not normal cats. These data indicate that the two types of central reflex mechanisms are activated by two distinct types of afferent pathways (A and C fibers).

Coincident with the physiological changes, an expansion of C-fiber afferent terminals was noted in the spinal cord using immunocytochemical techniques. This expansion occurred in lateral lamina I of the dorsal horn and in the area of the sacral parasympathetic nucleus. The C-fiber terminals were identified by their content of vasoactive intestinal polypeptide (VIP), a neuropeptide present only in sacral C-fiber afferents and in a high percentage of visceral afferents.

Other experiments identified important pharmacologic correlates to these anatomical changes. For example, following spinal cord injury the bladder excitatory action of intrathecally administered VIP was markedly enhanced. In normal animals VIP (1-10  $\mu$ g) consistently inhibited bladder reflexes; however, in paraplegic animals, VIP (0.1-2  $\mu$ g) facilitated bladder reflexes and promoted blad-

der emptying. Thus, various findings indicate that C-fiber afferent terminal fields and changes in the activity of a putative C-fiber afferent transmitter (VIP) are involved in the recovery of micturition reflexes and the development of bladder hyperactivity following spinal injury.

**Urethral obstruction in the rat.** In the rat, A-fiber rather than C-fiber afferents initiate spinal as well as supraspinal reflex mechanisms to the urinary bladder, whereas C-fiber afferents appear to only modulate micturition. One or both of these groups of afferents exhibit marked morphological changes under conditions of partial urethral obstruction. Obstruction of 6-weeks' duration leads to a hypertrophied bladder (5-7 times increase in weight), enhancement of the spinal reflex mechanism, and development of a hyperreflexic-unstable bladder. Axonal tracing studies using horseradish peroxidase (HRP) revealed an expansion (60 percent increase) of bladder afferent terminal fields in the spinal cord and a 45 percent increase in somal cross-sectional areas of labeled dorsal root ganglion cells innervating the bladder. Efferent postganglionic neurons in the major pelvic ganglion also exhibited a large increase (90 percent) in the cross-sectional area.

**Implications—**Two conditions (spinal injury and obstruction) in different species (rats and cats) produced similar gross changes in bladder function and similar morphological and electrophysiological changes in a spinal reflex pathway to the bladder. If these changes also occur in humans, then selective pharmacologic manipulation of the spinal reflex pathway may be effective in reducing the urinary tract dysfunctions occurring in paraplegic patients.

#### **Publications Resulting from This Research**

None reported.



## [90] A Clinically-Derived Protocol for Changing Condom Catheters in Males with Spinal Cord Injury

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—While meticulous hygiene and observation of the condom catheter and penis is consistently advocated, a disagreement exists on how often the condom catheter needs to be routinely changed. Recommendations range from changing it twice a day to changing it every few days. In fact, several of the most highly regarded nursing texts make no recommendation on how frequently it should be changed. Failure to reach a consensus on this issue is undoubtedly the result of the lack of any meaningful data upon which to base this clinically important decision.

The objectives of this randomized controlled clinical trial are: 1) to determine the incidence of urinary tract and penile skin complications for male patients with spinal cord injury (SCI) whose condom catheters are changed daily, every other day, or every third day; and, 2) to develop a protocol for routine changing of those catheters.

**Methodology**—The study population will include all male patients with SCI admitted to our hospital who use condom catheter urinary collection devices, are asymptomatic for urinary tract infection for at least 48 hours, and are free from other urinary tract and penile skin complications at the time of entry into the study.

Subjects will be randomly assigned to one of three groups: 1) patients whose condom catheters are changed every day (Group I); 2) changed every other day (Group II); and, 3) every third day (Group III). Routine inspection of the penile skin will occur whenever the catheter is changed regardless of study group assignment. Total study population will be 87 patients. The duration of the study will be 30 days for each patient. A single brand of condom catheter has been selected and will be used for all study subjects. Patients having numerous accidents related to an improperly fitting catheter will be dropped from the study. At the conclusion of the study, a protocol will be developed for routine changing of these catheters.

**Preliminary Results**—Patient recruitment has been slow due to the 30-day time factor. Ten patients have been enrolled into the study at this time.

**Future Plans**—Plans are to continue enrolling patients over the next 4 years.

**Publications Resulting from This Research**

None reported.

## [91] A Comprehensive Approach to Management of Infertility in Males with Spinal Cord Injury

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Infertility is a major problem among male spinal cord injury (SCI) patients. In fact, infertility rates range from 99 percent for neurologically complete quadriplegics to 90 percent for neurologically incomplete paraplegics. This study seeks to: 1) determine optimal conditions for producing seminal

emission via electrical stimulation of the pelvic sympathetic nerves; 2) compare electrical stimulation with strong vibratory stimulation of the genitalia in eliciting seminal emission in male SCI patients; 3) determine if repeated stimulation improves semen quality (sperm count, motility, and morphology); 4)

determine if intermittent testicular cooling improves semen quality; 5) relate success or failure of seminal emission production to neurologic level and extent of spinal lesion, urodynamic assessment of lower urinary tract function and incidence of recurrent urinary tract infection; and, 6) artificially inseminate a male SCI patient's female partner who has been unable to be impregnated since the patient's injury.

**Methodology**—Male SCI patients voluntarily participating in the study will be assigned to a 2 to 3 month trial in the vibratory stimulation group. Seminal emissions will be acquired and sperm counted and examined for viability. Patients failing to produce viable sperm will be entered into the electrical stimulation group if they wish to proceed. Patients who continue to fail to produce adequate numbers of viable sperm will undergo stimulation with testicular cooling. Caffeine stimulation will be performed on selected specimens to evaluate its effectiveness on improving sperm motility.

If these techniques produce no improvement in semen quality, the patient will be given the opportunity to participate in a study of direct aspiration of sperm from the surgically exposed vas deferens. Viability of sperm produced will be determined. The concomitant success or failure of seminal emission

production will be assessed statistically. Female partners of patients with satisfactory sperm production will be evaluated physically and if in good health, artificially inseminated.

**Preliminary Results**—Twenty-three patients have been entered in the study. A total of 17 patients have been entered into the vibratory stimulation group, and 16 patients have been entered into the electroejaculation group. Five patients have been entered into the trial of intermittent testicular cooling. All patients produced an ejaculate. Most had adequate sperm counts; however, motility has been less than 15 percent for all but two patients. The spouse of one of these patients is currently undergoing fertility assessment prior to artificial insemination. No female partners have been artificially inseminated to date.

**Future Plans**—Patients who are unsuccessful with both types of stimulation will be offered the opportunity to participate in a study of direct aspiration of sperm from the surgically-exposed proximal vas deferens.

#### **Publications Resulting from This Research**

None reported.

## **[92] Medical and Psychological Considerations Regarding the Surgical or Pharmacological Treatment of Impotence in Males with Spinal Cord Injury**

**L.K. Lloyd, MD**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Erectile dysfunction is prevalent in the spinal cord injury (SCI) populations as well as in other males with various forms of spinal cord dysfunction. For the last 15 years, various penile implants have been developed and utilized for erectile dysfunction; recently, pharmacological interventions have become available as well. Much of the existing literature concerning both of these procedures, particularly as it relates to SCI, has been focused on medical and/or physical complications, with very little attention paid to the impact of these procedures on sexual behavior, sexual satisfaction and/or relationships. This study will prospectively

evaluate the impact of both implant and injection procedures on sexual behavior, sexual satisfaction, and relationships in the SCI population.

**Methodology**—All couples are screened for evidence of relationship stability and desire to comply with the study protocol. In addition, they are assessed for psychological and physical health, including evidence of drug and/or alcohol abuse, prominent depression, and marital discord. Individuals showing evidence of any of these problems are referred to appropriate counseling or other treatment before beginning either the implant or injection procedure.



Once screening has been completed, the couple is assigned on a randomized basis to either the immediate treatment or delayed treatment group. Those in the immediate treatment group complete a battery of sexual behavior and satisfaction scales before the intervention (implant or injection) is initiated. Three months after the procedure has been completed, the couple repeats the same battery of forms.

In the delayed treatment group, a similar sequence occurs, except the battery is given 3 months prior to the intervention, and is followed with a second administration of the battery immediately prior to intervention. The battery is administered a third time 3 months post-intervention. This sequence of tests controls for spontaneous changes in sexual behavior and/or satisfaction which may occur simply as a function of time or idiosyncratic events.

**Preliminary Results**—Seven SCI persons and their partners have been enrolled in the implant or injection program. Very few SCI men are opting for implants anymore. Results to date indicate these interventions do not appear to make a major impact on sexual behaviors and/or frequency, but sexual self-esteem scales do seem to reflect improvement.

**Future Plans**—We will continue to recruit SCI men and their partners for both the implant and injection treatments and collect data from participants pre- and post-treatment.

#### **Publications Resulting from This Research**

None reported.

### **[93] Histopathology of Denervated Skin Following Spinal Cord Injury**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Skin complications represent a leading source of morbidity in the spinal cord injured population, yet relatively little is known about the histopathology of denervated skin. In order to improve the clinical management of these complications, and ultimately to prevent them, we are conducting a study to increase the understanding of precisely what happens at the cellular and tissue level when the body's largest organ, the skin, is denervated.

The objectives of this study are to: 1) describe and establish the histopathology of denervated skin in patients with spinal cord injury (SCI) using appropriate laboratory and electron-microscopic techniques; 2) establish the pathogenesis and natural history of skin changes following SCI; 3) determine the nature of the relationship between the neurologic level and extent of SCI and the occurrence of specific skin changes; and, 4) determine whether there is a meaningful correlation between the severity of post-SCI skin complications and possible

covariates such as the histopathologic changes observed, the neurologic level, and extent of lesion.

**Methodology**—Skin punch biopsies are obtained from patients with SCI who have injuries that are neurologically complete, sensory sparing only, or motor nonfunctional. Study patients are divided into three groups by level of injury; 1) T6 and above; 2) T7-T11 with sacral reflexes present and upper motor neuron evidence to legs; and, 3) T12 and below with absence of sacral reflexes and lower motor neuron loss to legs. Biopsy specimens are obtained from a group of patients who have chronic SCI, more than one year post-injury, as well as a prospective group of patients who were injured less than two months prior to the time the skin biopsy was obtained. Skin biopsies will be examined by a dermatopathologist using histopathologic methods of examination. In addition, a subset of the biopsies will be studied by electron microscopy.

**Preliminary Results**—Thirteen biopsies have been obtained: seven in the chronic phase and six in the prospective phase. Twelve of these biopsies have been submitted for electron microscopy examination. Results of the examinations are pending.

**Future Plans**—Studies of biopsy specimens in the

chronic group will continue. We will also start to evaluate early results from these biopsy specimens to see if the histopathologic findings are related to the level of injury.

**Publications Resulting from This Research**

None reported.

## **[94] Natural History and Clinical Course of Skin Complications (Excluding Pressure Ulcers) in Persons with Spinal Cord Injury**

**Samuel L. Stover, MD**

University of Alabama at Birmingham, Birmingham, AL 35294

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Persons with spinal cord injury (SCI) frequently develop an array of potentially serious skin complications in addition to the more dramatic pressure ulcer typically associated with spinal paralysis. Examples include superficial and deep bacterial and/or fungal infections, furuncles, abscesses, dermal fibrosis, paronychia and a host of related changes affecting the nail plate, bed, and wall. Our experience is that nonpressure ulcer skin complications represent a more significant and serious source of morbidity in this population than generally acknowledged.

The objectives of this study are to: 1) establish a clinically useful method to document the occurrence, etiology, definitive characteristics, management, and treatment outcome(s) of all nonpressure ulcer skin lesions occurring in a series of patients with SCI; 2) determine the nature of the relationship(s), if any, between nonpressure ulcer skin lesions in patients with SCI and specific characteristics of the spinal injury itself (e.g., neurologic level and extent of lesion, time post-injury, etc.); and, 3) develop, print, and distribute a clinically-oriented, teaching/training monograph devoted to the photographic documentation and description of nonpressure ulcer skin lesions in patients with SCI.

**Methodology**—A data collection instrument has been developed, refined, and field tested to document nonpressure ulcer skin complications in pa-

tients with SCI. A history is obtained and a physical examination is performed at the patient's annual follow-up examination. A clinical nurse specialist examines the patient's skin and completes the data collection forms. Data are obtained by actual observation of the patient. When possible, a diagnosis of the skin lesion(s) is made. Skin lesions are documented by photographs. When appropriate, bacterial and/or fungal cultures are acquired and appropriate treatment is given.

The analysis will be stratified by potential risk factors such as neurologic level and extent of lesion, age group, sex, and time post-injury. A high quality, clinically-oriented monograph will be produced by the project team.

**Preliminary Results**—Data collection instruments have been field tested on 152 patients. Techniques have been refined for photographing skin lesions at a close range. One hundred and eighty photographs have been taken of 31 patients with various skin lesions.

**Future Plans**—The goal is to obtain data on 250 to 400 patients annually. As additional data become available, preliminary analyses will be made to evaluate the progress of the study.

**Publications Resulting from This Research**

None reported.



## [95] Natural History and Clinical Course of Urinary Tract Complications in Patients with Spinal Cord Dysfunction

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Sponsor: National Institute on Disability and Rehabilitation Research

**Purpose**—Appropriate clinical management of patients with neurogenic bladders resulting from spinal cord dysfunction requires: 1) knowledge of the natural history or clinical course of urinary tract complications in this group; and, 2) data from which to determine if urinary complications in this group are predictable from early post injury urinary tract status and method of early bladder drainage management. The objectives of this study include: 1) to document the natural history and clinical course of urinary tract complications in persons with spinal cord injury (SCI) by continuing to build a urology database; 2) to answer specific research questions addressing the effects of *a*) various bladder drainage management methods; *b*) various bacterial pathogens; and, *c*) various demographic factors (including age, sex, etc.) on long term renal function, measured by effective renal plasma flow (ERPF), and the development of urologic complications including orchitis and/or epididymitis, penoscrotal abscess, penoscrotal fistula, ureterectasis, pyelocaliectasis, and calculi in a population with SCI; and, 3) to develop, refine, and offer for extramural acquisition a transportable urologic complication data collection protocol and its associated database. One of the specific research questions is addressed: “What is the incidence of clinically significant urologic complications in females with spinal cord injury?”

**Methodology**—Data are collected for each patient admitted to the University of Alabama–Spinal Cord Injury Care System (UAB-SCICS) at admission, discharge, and annually thereafter. In addition, data have been collected retrospectively on 596 patients admitted to the UAB-SCICS between 1970 and 1979; prospective data are collected on these patients as they return for their annual follow-up examinations.

In our study of the incidence of urologic complications in females, patients were stratified by known risk factors (including method of bladder drainage management and neurologic level and

extent of lesion). The incidence of each urologic complication was then calculated for both females and males.

**Preliminary Results**—Complete studies have been performed and data recorded on 327 patients from a retrospective study group and 801 patients from a prospective group, thus yielding 1,128 completed studies to date.

Currently, in a study of 110 females injured between 1973 and 1985, multiple linear regression was used to assess the effects of neurologic classification method of bladder management and renal complications on renal functions at discharge and up to 10 years post injury. However, bladder management methods and neurologic classification showed no statistically significant effect on renal function. Conclusively, the method of bladder management in females does not adversely effect long term renal function.

A second study compared 42 females with 186 males injured between 1973 and 1984 according to age, race, neurologic level and extent of lesion, method of bladder management, and incidence of secondary urologic complications during the first 4 years post injury. No statistically significant differences between males and females were found when multivariate statistical techniques were used to control for the possible confounding effects of age, race, bladder drainage management, neurologic level and extent of lesion.

**Future Plans**—Five additional research questions have been included: 1) What are the effects of various bladder drainage management methods on long term renal function in persons with SCI? 2) When are persons with SCI at greatest risk for developing clinically significant urologic complications? 3) What is the optimal schedule for routine urologic follow-up of persons who have experienced a spinal cord injury? 4) What is the effect of external sphincterotomy on long term urologic func-



tion in persons with spinal cord injury? and, 5) Are the consequences of renal calculi more serious in older than younger persons with SCI? The second and third research questions will be addressed during the next year.

## **[96] Pathologic Effects of Recurrent Bacteriuria in Patients with Spinal Cord Dysfunction**

**K.B. Waites, MD**

University of Alabama at Birmingham, Birmingham, AL 35294

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Urinary tract infections (UTIs) are a serious source of morbidity for spinal cord injury (SCI) patients. Recurrent hospitalizations and outpatient services required for treatment of acute and chronic UTIs are extremely expensive and may impede both the rehabilitation process and vocational pursuits. In addition, UTIs may lead to grave urologic complications and, in some cases, eventual renal failure. There is a need to prevent these infections and their sequelae; this would improve the overall rehabilitation potential and quality of life for SCI patients.

Objectives of this study include: 1) determination of the incidence of clinically significant urinary tract complications coincident with the major bacterial species; 2) determination if aggressive treatment of most pathogenic organisms results in fewer long-term secondary urinary tract complications; 3) determine if patients with certain human leukocyte antigen (HLA) combinations are at unusually high or low risk for developing long-term secondary urinary tract complications; 4) determine if the phagocytic activity of human leukocytes correlates with the incidence of clinically significant UTIs and long-term secondary complications; 5) determine if the degree of bacterial adherence to the urothelium correlates with the incidence of clinically significant UTIs and specific HLA combinations; and, 6) determine the prevalence of *Mycoplasma hominis* and *Ureaplasma urealyticum* in lower and upper urinary tract (where possible in selected patients with spinal cord injuries), and the association of these organisms with various pathologic conditions, with particular emphasis on upper urinary tract disease and calculi.

## **Publications Resulting from This Research**

None reported.

**Methodology**—Records of SCI patients evaluated in the outpatient clinics at Spain Rehabilitation Center are being evaluated to determine the presence of UTI, the species of organisms involved and type(s) of urologic complications which occur over time. The incidence and severity of urinary tract complications secondary to chronic or repeated infections is documented in successive follow-up visits in a group of SCI patients who are either newly injured or are within 2 years of the initial injury. This group is followed at quarterly intervals and treated aggressively for infection. These patients will be compared to those who are evaluated only once each year.

Also, a group of patients (subjects) who are chronically infected and have diminished renal function and a separate group (controls) who have consistently sterile urine or whose sole complicating diagnosis is bacteriuria have been identified from our patient database. Fifty patients from each of these two groups will have tests performed at the time of their annual urologic evaluation to determine the phagocytic abilities of their peripheral blood neutrophils, the degree of adherence of bacteria to the urinary bladder epithelial cells in those who are infected, and for the determination of HLA haplotypes. Leukocyte phagocytic activity and bacterial adherence will be correlated with incidence of clinically significant urinary tract complications and with particular HLA combinations. Finally, the prevalence of mycoplasmas in urine specimens from SCI patients will be determined.

**Preliminary Results**—The first two years of this project have been devoted to perfecting laboratory techniques. Presently, we are evaluating the concur-



rent bacteriologic status of all patients with positive urine cultures for mycoplasmas. So far, these studies indicate that mycoplasmas colonize the bladders of persons with frequent urinary tract instrumentation just as conventional bacteria do.

#### **Publications Resulting from This Research**

None reported.

### **[97] Clinical Research Center for Acute Spinal Cord Injuries**

**Wise Young**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—This project is a continuation of the Clinical Research Center for Acute Spinal Cord Injuries at New York University. The underlying theme of this Center is to study intensively experimental spinal cord injury at a basic pathophysiologic level as a model for clinical spinal cord injury.

Major emphasis will be placed on studying the effects of trauma to the spinal cord beyond the acute period following the injury. Changes in the distribution of ions such as calcium, sodium, and potassium within the cord, neurophysiologic studies of ascending and descending pathways, and the role of cellular inflammatory response as a cause of progressive damage to the spinal cord in the weeks following the trauma will be used to test the hypothesis that the injury to the spinal cord is progressive beyond the first 12-24 hours. This will provide important information about treatment regimens which may have to be utilized for extended periods if any recovery is to be achieved.

In addition to determining these pathophysiologic changes in the spinal cord, the effect of

different treatment modalities on these parameters will be tested. The clinical studies will examine the efficacy of opioid antagonists and corticosteroids in the amelioration of spinal cord injury as part of a multi-center randomized trial. Alternate therapies will also be tested in pilot studies. Experimental treatment will test the hypothesis that the opioid receptors play a role in spinal cord injury and that this therapy and corticosteroids are effective even when administered more than 1 hour after injury. The evaluation of therapy on the recovery of injured animals will include neurologic, physiologic, and morphologic outcome parameters. This will provide a comprehensive picture of the experimentally-injured spinal cord and the response to therapy that will provide a rational basis for selecting clinical therapies. The goal of a Center for Spinal Cord Injury will be realized by the close integration of the component projects of this proposal.

#### **Publications Resulting from This Research**

None reported.

### **[98] Gallstone Disease in Patients with Spinal Cord Injury**

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**Sponsor:** *Paralyzed Veterans of America*

**Purpose**—Spinal cord injured (SCI) patients are at a high risk for various medical complications, including kidney stones, debilitating constipation, and

colon cancer. Except for our preliminary study there are no published data concerning gallstones and SCI patients. The purpose of this study has been to study

the incidence of gallstone disease in acute and chronic SCI patients and to determine if gallbladder motility is abnormal.

**Progress/Preliminary Results**—The incidence of gallstone disease (24 percent) was higher in the SCI group than in the normal control group (10 percent). The incidence of gallstones following acute SCI injury was 32 percent. Preliminary results have found that the SCI group had abnormal gallbladder motility.

**Future Plans/Implications**—Future plans include a determination of gallstone formation and gall-

bladder motility in patients with different levels of injury. Ultrasound findings will be correlated to abdominal radiographs to determine the prevalence of cholesterol versus pigment gallstones. Knowledge of the type of gallstone will be important in developing preventive or early treatment programs for gallstone disease in SCI.

#### **Publications Resulting from This Research**

None reported.

### **[99] Comparison of Clean and Sterile Intermittent Catheterization Methods in Hospitalized Patients After Spinal Cord Injury**

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*Sponsor: American Association of Spinal Cord Injury Nurses*

**Purpose**—It is the purpose of this study to determine the risk of urinary tract infection associated with two intermittent catheterization techniques (sterile and clean), during in-patient hospitalization. Since it is not common practice at The Rehabilitation Institute of Chicago to prescribe prophylactic agents when intermittent catheterization is initiated, the study will be performed with patients who are not using these agents at the time of initiating the procedure. Specific objectives are to: 1) compare the incidence of infections in patients using clean intermittent catheterization technique with those using sterile technique; 2) determine the incidence of resistant infections using the two catheterization techniques; and, 3) determine the relationships between time interval between catheterization, urinary volume, type of organism in the urine, and incidence of infection.

**Progress**—To date, 32 patients were recruited and data has been completed on 30. The intended goal is 50 subjects, and the study will be extended to achieve this number. Difficulties in recruitment include: 1) number of patients with incomplete injuries (excluded); 2) patients who cannot meet the requirement of having less than 100,000/ml colony

count to begin the study; and, 3) numbers of patients for whom intermittent catheterization is not a goal.

**Preliminary Results**—Some preliminary results are as follows: 1) the mean number of days prior to experiencing a colony count per ml of urine of more than 100,000 were: a) clean—13.5; and, b) sterile—18.4; 2) some urine cultures of both groups have remained sterile throughout the entire study; 3) clinical infections occurred in the clean group, but none in the sterile group; 4) some patients in each group developed asymptomatic bacteriuria (100,000/ml); and, 5) some patients in the sterile group developed bacteriuria less than 100,000/ml.

It is important to note that an adequate representative field was not developed when the results described briefly above were observed.

**Implications**—Clean intermittent catheterization, if proven safe for hospitalized patients, would result in cost benefits related to equipment and staff time required to implement the procedure and to teach patients self-care. The procedure is simpler and time-efficient, facilitating compliance after discharge. Also, confusion created by switching tech-



niques (clean versus sterile) because of discharge would be minimized.

**Publications Resulting from This Research**  
None reported.

### **[100] Prophylaxis for Deep Vein Thrombosis in Acute Spinal Cord Injury Comparing Two Doses of Low Molecular Weight Heparin During the First Two Weeks Following Injury**

**Geno J. Merli, MD; Barbara Rensman, BSN; Linda Doyle, BSN; Sarah Crabbe, PharmD; Angela Sciarra, PharmD; Leigh Hopkins, PharmD; John Ditunno, MD**  
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**Sponsor:** *Spinal Cord Research Foundation of Paralyzed Veterans of America*

**Purpose**—The goal of this study is to optimize a method of prophylaxis for deep vein thrombosis (DVT) during the first two weeks following acute spinal cord injury. Evaluation of the safety, efficaciousness, and practicality of two different doses of low molecular weight heparin (ORG 10172; 750  $\mu$ , SC, BID and 1250  $\mu$ , SC, QID) plus external pneumatic compression as prophylaxis in the first two weeks following injury will be made.

**Methodology**—This is a pilot study which is double-blinded, randomized, and prospective. Fifty patients, C2 through T12, motor complete and incomplete-preserved motor, nonfunctional, and less than 7 days of injury, will be entered into the protocol. All patients will have daily  $^{125}\text{I}$  fibrinogen scanning. Venous imaging (duplex scanning) will be performed at the completion of weeks Two and Four. All positive noninvasive testing is confirmed by venography. Factor Xa and IIa levels will be obtained at baseline and once weekly for two weeks.

**Progress**—Twenty-five patients have been entered into one of two doses of ORG 10172. One patient was dropped due to protocol violation.

**Preliminary Results**—Four of 24 (16.6 percent) patients developed DVT on Day 6, 7, 8, and 14, respectively. Two of the four had calf vein thrombosis, one with calf and popliteal, and one with isolated proximal vein thrombosis. Since the study continues to be blinded, no relationship can be determined between dosage and DVT incidence.

**Future Plans/Implications**—Twenty-five additional patients will be entered over the coming year. The trend is very encouraging since our previous work reported an incidence of 7 percent in electrical stimulation and 10 percent in external pneumatic compression, both with concomitant low dose heparin.

**Publications Resulting from This Research**  
None reported.

## **C. Spinal Cord Regeneration**

### **[101] Toward Better Methods of Nerve Repair and Evaluation**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #B003)*

**Purpose**—The major limitation of peripheral nerve repair has been the matching of specific axon-to-axon connections to reestablish correct communica-

tion channels within the peripheral nervous system following the transection of a nerve. The initial purpose of this project was the development of a

microelectronic silicon chip neuroprosthesis for nerve repair at the axon level that would enable specific axon-to-axon connections. This nerve chip should be a general purpose device with multiple applications. These applications would include limb prostheses, functional electrical stimulation, and basic biological research.

**Methodology**—Nerve chips with laser-drilled holes and plasma-drilled holes were implanted in both rat and primate peripheral nerves. Holes diameters were from  $25\mu$  to  $8\mu$ . The animals were evaluated from 1 month to 1 year following implantation. They were evaluated by histological, physiological, and functional methods for axonal regeneration.

**Progress**—Initial work has shown the feasibility of growing axons through laser-drilled holes in silicon chips. Fabrication techniques have been developed to create holes through the chips that are compatible with microelectronics by using plasma techniques. We have also demonstrated regeneration through these plasma-etched holes. Electrode materials are being developed to allow stable long-term contact with nerves. Passivation methods are being worked out to protect the chip within the biological environment. Present work is in progress that will allow direct communication between individual regenerated axons and microelectrodes fabricated on the surface of the chip.

**Results**—Histological results for the short-term (1 to

3 months) animals demonstrated regeneration of the axons through the  $25\mu$  and  $8\mu$  holes. Histological and physiological results for the long-term animal (6 to 12 months) demonstrated regeneration of the axons through the holes with physiological conduction across the chip. Similar results have been obtained in chips with plasma-etched holes.

**Future Plans**—Our overall goal is to provide a means for repair of nerve function. This includes cases of nerve injury within intact limbs where the erroneously routed signals in regenerated axons would be rerouted to their appropriate destinations. Repair in the case of severed limbs would consist of interfacing from the nerve stump to a motor/sensory prosthesis. Repair in the case of spinal cord injury would involve either mapping of information from nerve above the injury into nerve below the injury or direct computer control for functional neuromuscular stimulation. It is felt that all of these modes of nerve repair can be achieved using a general purpose neural interface that is capable of recording from and stimulating single or small groups of axons at the repair site. The first clinical milestone will be the development of directly interfaced limb prosthesis.

#### Publications Resulting from This Research

**Advances Toward Development of Microelectronic Axonal Interface Neuroprostheses.** Kovacs GTA, Stormont CW, Hentz VR, Rosen JM, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 292-293, 1989.

## [102] Research and Development of an Artificial Nerve Graft

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B387-RA); State of California Grant in Competitive Technology; Genentech Corporation

**Purpose**—Indications for nerve grafting vary from gaps of 1 cm to greater than 5 cm before a graft would replace an end-to-end repair under tension. Where a graft is indicated, autografts are the preferred method at present. The autograft fulfills three major requirements for an ideal nerve graft: 1) it acts as a passive conduit for axonal regeneration; 2) it is a natural substitute that is immunologically

acceptable; and, 3) it is vascularized by the recipient bed as a free graft.

The major limitation of the autograft is the requirement of a donor nerve. Homografts and heterografts have been evaluated as an alternative to autografts but have been found to be immunologically unacceptable. Therefore, the development of an artificial nerve graft is necessary to solve both



problems of availability and rejection by the immune system.

**Methodology**—Artificial nerve grafts (ANG) have been fabricated from a number of materials for our laboratory. The artificial nerve grafts are constructed from a conduit filled with a regeneration medium. The regeneration medium may contain cellular and/or noncellular elements. The conduit materials have included resorbable and non-resorbable man-made polymers and natural materials such as collagen. Regeneration medium has consisted of various collagen types in several different structural configurations.

The collagen is being used in several studies as a matrix for the addition of diffusible factors (nerve-growth factor and insulin-growth factor) and for Schwann cells grown in tissue culture. The ANG have been implanted in both rat (peroneal nerve) and nonhuman primate (median and ulnar nerves) animal models. The nerve regeneration has been evaluated through qualitative and quantitative histology, quantitative physiology, and functional methods.

**Progress**—We completed several studies evaluating collagen as a medium for nerve regeneration. Recently, we began studies evaluating the effects of growth factors and Schwann cells on nerve regeneration. In addition, we have used several different types of conduit materials for the ANG's, including Dexon and Maxon provided by Davis and Geck of Pearl River, NY. More recently, we began to explore conduits with porous walls to allow exchange of

nutrients and factors, but to prevent the migration of cells. These were provided by Menlo Care of Palo Alto, CA. We have also developed an *in vitro* assay using dorsal root ganglion explants to evaluate the numerous growth factors available for study.

**Results**—Our initial study using Zyderm collagen implant (Collagen Corporation, Palo Alto, CA) demonstrated that nerves will regenerate across gaps (0.5 cm) filled with collagen in the rat model. However, the regeneration was inferior to the regeneration across sutured autografts (SAG). A subsequent study in the rat model has shown that using a different form of collagen obtains results equivalent to using a sutured autograft. We have also completed a study comparing several types of materials as conduits for ANG's. These results are being compiled for publication.

**Future Plans**—The ideal artificial nerve graft would allow regeneration across long gaps. This ANG should probably have a conduit which is flexible, transparent, resorbable, and has porous walls that control the internal milieu. In addition, this conduit should be filled with a matrix ideal for the regenerating axons. This may require addition of growth factors, cells, and scaffolding proteins, i.e., laminin, fibronectin and collagen.

#### Publications Resulting from This Research

**Artificial Nerve Graft Compared to Autograft in a Rat Model.**  
Rosen JM, Pham HN, Abraham G, Harold L, Hentz VR, *J Rehabil Res Dev* 26(1):1-14, 1988.

### [103] Timing of Transplantation for Spinal Cord Injury

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Sponsor: American Paralysis Association

**Purpose**—The present experiment was undertaken to evaluate the ideal time interval that should elapse in order to achieve satisfactory incorporation of transplant tissue at the site of cord injury in a weight-drop contusion model in a rat.

**Methodology**—A series of 18 Sprague-Dawley rats

were subjected to a weight-drop contusion injury, previously standardized in our laboratory. A 10-gm weight was dropped from a height of 2.5 cm, onto the exposed dura of the spinal cord at the T8 level. In different groups of animals, injection (transplantation) of neocortical tissue (2  $\mu$ l) into the site of cord injury was made at different time intervals



following the impact injury of the cord. The intervals were immediate, 1 day, 3 days, 7 days, 14 days, and 21 days. Three animals were assigned to each time interval. Immediately prior to the transplantation, neocortical tissue was obtained from the fetuses of timed pregnant rats at day 16 of gestation. The injured rats were sacrificed 14 days after transplantation.

**Progress**—In 13 of the 18 animals, there was excellent incorporation of the transplant neocortical tissue. However, the graft was successful in only one of the three in the immediate group, and in two of the three animals at 1 day and 3 days, respectively. At 7 days and at 14 days, all three of the animals in each group showed excellent graft incorporation, with filling of the cavity left at the site of cord injury. At 21 days, two of the three showed satisfactory transplantation.

Histological examination at the time of sacrifice revealed the evidence of growth and differentiation of the transplant tissue. There was a sharp interface between the transplant and the residual spinal cord tissue. While the initial neocortical tissue consisted of neuroblasts, the graft at two weeks post-transplantation showed fully differentiated, nondividing neurons, including neuropil. It was not possible to determine in these experiments whether the growth of the graft was such that there was regeneration or communication with residual spinal cord tissue.

**Future Plans/Implications**—The next step in these experiments will entail an evaluation of regeneration (using special stains) and behavioral studies of functional recovery.

#### **Publications Resulting from This Research**

None reported.

### **[104] Rebuilding of a Functional Motoneuronal Innervation of Deafferented Muscles after Excitotoxic Lesion of the Ventral Spinal Cord**

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**Sponsor:** INSERM, Paris, France; American Paralysis Association

**Purpose**—The excitotoxic lesion of lumbar spinal cord neurons in the adult rat reproduces muscular paralysis and atrophy characteristic of human pathologies such as amyotrophic lateral sclerosis or poliomyelitis. These functional alterations are clearly related to neuronal loss in the ventral and intermediate horns, including motoneuronal pools. In contrast, target-deprived afferent fibers remain in the spinal cord lesion. Transplanted homotypic embryonic neurons have been shown to grow and differentiate in various excitotoxically neuron-depleted areas and may receive projections from host afferents previously deprived of target-neurons.

The present study, therefore, sought to describe the development of fetal spinal neurons implanted into an adult excitotoxically-lesioned lumbar spinal cord and characterize any resemblances between the graft neural circuitry and that of intact spinal cord, including the growth of an axon outside of the spinal cord into a guide.

**Methodology**—A region of the lumbar enlargement of rat spinal cord received a kainate injection aimed at the ventral horn. One week later, fetal spinal cells were transplanted as a suspension into the lesioned area. Either simultaneously, or one week later, an autograft of peroneal nerve (PN) was performed. One end of the PN was grafted into the area occupied by the neural transplant. The other end was ligatured and driven outside the central nervous system (CNS).

In one series of experiments, axons of transplanted neurons growing into the PN graft were labeled two days before sacrifice by retrograde tracing, using wheat germ agglutinin-horseradish peroxidase (WGA-HRP) from the cut distal end of the PN graft. Tissue was subsequently processed for HRP histochemistry using TMB. In this and other series, the rats were perfused with aldehydes and their spinal cord serially cut on a freezing microtome or a vibratome (40 to 50 $\mu$ m). To study host-to-graft



afferents, peroxidase immunocytochemistry was carried out using specific antibodies raised against serotonin (5HT; 1/10,000), noradrenaline (NA; 1/5,000), tyrosine hydroxylase (TH; 1/3,000) and calcitonin-gene-related-peptide (CGRP; 1/10,000). In all cases, spinal cord areas containing grafted neurons were visualized on sections Nissl-stained with cresyl violet. A few vibratome-sections were processed for regular electron microscopy, post-fixed with  $\text{OsO}_4$ , dehydrated and embedded flat in epon. Transplants were trimmed out from plastic-embedded sections and thin sections were stained with uranyl acetate and lead citrate.

**Results**—The neural grafts were generally large, occupying most of the neuron-depleted area. Some neurons which were very large and darkly stained with cresyl violet, resembled motoneurons; they were scattered in the transplants. At the electron microscopic level, grafted cells reconstituted a neuropil with characteristics comparable to those of a normal adult CNS.

In the spinal cord dorsal and intermediate horns, CGRP is normally essentially contained in primary afferent C fibers. Numerous CGRP-ir fibers were also present in transplants extending dorsally into the superficial dorsal horn, intermingling with grafted neurons. Most of these fibers could be traced back to the dorsal root entry zone. Immunocytochemistry of 5HT, NA, and TH was used to reveal host monoaminergic afferents descending from brainstem nuclei, and to analyze their connectivity with grafted neurons. 5HT, NA, and TH immunoreactive fibers were present in the neural transplants.

Transplanted neurons, which had an axon implanted into the PN graft as a guide, were identified using retrograde tracing with WGA-HRP from the cut distal (extra-spinal) end of the PN graft. Twenty to fifty labeled neurons were observed in all neural transplants in which a PN graft had been successfully implanted. They were large or very large size, i.e., they resembled motoneurons.

**Results/Implications**—Several transplant studies have already been carried out, looking at the growth and integration of fetal spinal transplants in the lesioned spinal cord. They were essentially defining the ability of neural transplants to limit the effects of a section of the spinal cord. In our studies, excitotoxic lesions of spinal neurons of the intermediate and ventral horns were performed (without any direct lesion of spinal pathways) to reproduce some of the defects observed in neurodegenerative diseases such as amyotrophic lateral sclerosis. The results obtained in our studies of spinal transplants demonstrate that, in these conditions, fetal neurons can be connected by host afferents and, therefore, integrate the host neural circuitry. The other main result is the demonstration that grafted neurons can grow axons into a guide, outside of the spinal cord, which may eventually provide a structural and functional basis for neuromuscular reconnection. Experiments in which the distal end of the PN graft would be implanted into a denervated muscle remain, however, to be done.

#### **Publications Resulting from This Research**

None reported.

## **[105] Nerve Regeneration Through Synthetic Guidance Channels**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—The purpose of our study is to explore nerve regeneration through synthetic guidance channels. The mechanisms underlying nervous system regeneration are poorly understood. Consequently, conceptual background to plan interventions is

limited, and recovery following peripheral nerve injuries remains highly variable and incomplete.

Central nervous system injuries, including those to the spinal cord, are rarely associated with any appreciable return of function. Synthetic guidance

channels can serve effectively as tools to study the regeneration process, and may be utilized clinically in the repair of injured nerves. In the past, synthetic guidance channels have been considered as inert conduits providing axonal guidance, maintaining growth factors, and preventing scar tissue invasion. Little or no emphasis has been placed on the relationship between the physicochemical properties of the channel as related to the outcome of regeneration.

The guidance channel can be considered as a biomaterial that actively participates in the regeneration process by influencing the cellular and metabolic aspects of regeneration. Two channel characteristics that influence peripheral nervous system regeneration are permeability and electrical activity. The transfer of solutes across the channel walls directly influences peripheral nerve regeneration.

The permeability characteristics regulate the movement of nutrients and growth or trophic factors, thus influencing the degree of axonal growth within the channel. Guidance channels composed of electrically-charged polymers provide an attractive channel material, since they preclude the need for an external power source or electrical circuitry. Piezoelectric guidance channels significantly enhanced peripheral nerve regeneration compared to non-piezoelectric tubes of the same chemical composition.

#### **Publications Resulting from This Research**

**The Role of Biomaterials in Peripheral Nerve Regeneration.** Aebischer P, in *UCLA Symposia on Molecular and Cellular Biology, New Series*, R. Skalak, C.F. Fox (Eds.), 80-86, New York: Alan R. Liss, Inc., 1988.

### **[106] Regeneration and Functional Recovery in Neural Tissue**

**Mary B. Bunge**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—Our overall goals are to increase fundamental knowledge of factors that govern peripheral nervous system (PNS) and central nervous system (CNS) nerve fiber growth and maintenance, as well as survival of the parent neuronal cell body, and to better understand mechanisms involved in the development of connections, adaptation, and behavioral plasticity in different areas of the CNS.

Individual projects seek to investigate: 1) nonneuronal cell secretory products (both soluble and insoluble) that promote CNS neurite growth and neuronal survival in the animal and in culture; 2) regenerative potential of cultured CNS growth cones under differing environmental conditions to better understand differences in growth capacity; 3) distribution and molecular associations of myosin, actin, and several actin-associated proteins in cultured growth cones to clarify mechanisms responsible for oriented growth of neuronal processes; 4)

improving functional recovery following nerve repair by ameliorating the response of sensory neurons to injury with the administration of nerve growth factor; 5) the role of synaptic transmitters in visual cortex development; 6) physiological and morphological substrata for the process of adaptation of the vestibulo-ocular reflex; 7) response properties and connections of surviving somatic sensory cortex receiving cortical lesions in infants versus adults to search for the basis of observed behavioral recovery in the infant; and, 8) cerebellar unit and spindle afferent firing, reflex EMG changes, and stiffness and damping of the monkey's wrist during prevention of oscillations produced by novel loads through adaptive (plastic) control of movement behavior.

#### **Publications Resulting from This Research**

**None reported.**



## [107] A Center for Acute Spinal Cord Injury

**William F. Collins, Jr.**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—This program is designed as a coordinated effort to identify basic cellular mechanisms influencing degeneration and regeneration in the central nervous system (CNS) following injury. The goal is to develop a body of knowledge sufficient for identifying and understanding basic mechanisms which may be susceptible to intervention strategies leading to an improvement in neurological outcome. The program is divided into six major areas: 1) a core facility providing for electronmicroscopy studies; 2) a core facility providing for administrative support; 3) studies focused on trophic factors and membrane components that may influence regeneration; 4) analyses of mechanisms influencing sprouting and reactive synaptogenesis; 5) characterization of functional capacities of regenerating neurons including the activity of voltage-dependent channels;

and, 6) cytochemical and genetic mechanisms underlying regeneration and the role of the genome in reactivating specific developmental genes potentially important in regenerative responses.

**Implications**—These studies will fill critical gaps in our current understanding of regenerative responses in the developing and adult CNS. This knowledge is not only crucial for the development of successful strategies for treating spinal cord injury, but also for injuries elsewhere in the CNS, as well as disease processes involving the progressive loss of populations of neurons such as that which occurs in Alzheimer's dementia.

### **Publications Resulting from This Research**

None reported.

## [108] Spinal Cord Injury Research Center

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—Spinal cord injury and its eventual outcome is a product of the cellular and molecular mechanisms of degeneration, growth and regeneration. These processes may be best understood by a combination of studies which examine the acute and chronic mechanisms of degenerative phenomena. In addition, since the capacity to regenerate spinal neurons is limited in the adult spinal cord, an attempt will be made to examine regenerative phenomena during development when such phenomena are enhanced. The specific aspects of these phenomena to be explored include: 1) the biochemical pathophysiology of degeneration; and, 2) the physiology, biochemistry, and anatomical characterization of reorganization of nervous tissue subsequent to nerve trauma.

Further development and evaluation of a new injury device is an important step toward the control

of injury as an independent variable. Alterations in lipids, membrane integrity and recovery, and the ability to induce changes in the metabolic ( $\text{PO}_2$ ) or ion ( $\text{Ca}^{++}$ ) microenvironment will be studied to assess the effects of ischemia or impact injury to the spinal cord. Interventions into this pathological process will also be attempted with naloxone to improve tissue oxygenation and spinal hypocalcemia. The degree to which such interventions are successful will also be assessed chronically by behavioral or morphometric analysis.

Mechanisms of axolemmal synthesis are to be studied by assessing ganglioside contributions to peripheral nerve trauma. Reorganization and regenerative phenomena will be assessed in the cat and developing frog respectively using horseradish peroxidase (HRP) histochemistry, intracellular neurophysiological techniques, and electron micros-

copy. The role of nerves in the regenerative plasticity involved in limb regeneration is also to be assessed. Only by studying acute alterations in spinal pathophysiology and attempting to reverse them chronically, can we begin to effect changes in the capacity of the central nervous system to use the

inherent mechanisms of regeneration that it had, but may have lost, during development.

#### **Publications Resulting from This Research**

None reported.

### **[109] Leupeptin in Recovery After Nerve Repair**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—This study addresses the effects of calcium activated neutral protease inhibition by the tripeptide, leupeptin, on the muscle and peripheral nerve after nerve injury. The combined histological, ultrastructural, biochemical, toxicological, and functional studies are designed to confirm and expand on leupeptin's *in vivo* inhibitory effects on this enzyme in both muscle and neural tissue. Calcium activated neutral protease has been convincingly implicated in mediating both Wallerian degeneration and secondary denervation muscle atrophy.

**Progress**—The effects of leupeptin on the repair of injured nerve have been examined. The transected nerves were sutured completely immediately after injury in monkeys; half of the animals received leupeptin injections twice daily.

**Results**—Treated animals showed faster (toward normal) conduction velocities in the injured nerve than did the control animals, indicating a positive effect of the leupeptin on the regenerative process.

#### **Publications Resulting from This Research**

**Localization and Inhibition of Calcium Activated Neutral Protease (CANP) in Primate Skeletal Muscle and Peripheral Nerve.** Badalamente MA, Hurst LC, Stracher A, *Exp Neurol* 98:357-369, 1987.

**Localization of Calcium Activated Neutral Protease (CANP) in Denervated Human Skeletal Muscle and Peripheral Nerve.** Hurst LC, Badalamente MA, Stracher A, *Neuro-Orthopedics* 4:55-61, 1988.

**Peripheral Nerve Injuries and Entrapments: Nerve Injuries in the Upper Extremity.** Hurst LC, Badalamente MA, Paul S, Coyle MP, in *Principles of Orthopedic Practice*, 666-671, R. Dee, E. Mango, L. Hurst (Eds.), New York: McGraw-Hill Book Company, 1988.

### **[110] Recovery and Regeneration After Spinal Neuron Injury**

**Edward R. Perl**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—This program of projects is a continuing investigation of the effects of injury to spinal nerves or to spinal cord tracts upon the functional organization of vertebrate spinal neurons. The overall goal is to provide data on the degree that functionally-effective regeneration or reorganization of spinal neurons and their connections can take place in immature or mature vertebrate nervous systems. Each of the projects has its counterpart or point of departure in deficits suffered by human beings after

disease or traumatic injury of the spinal cord and/or of the nervous processes of spinal neurons.

The approaches are interdisciplinary and employ animal models in which combinations of physiological, morphological, biochemical, and behavioral measures are combined in various ways to test for examples of: 1) regeneration or reorganization of spinal pathways in vertebrates; 2) changes in the organization of spinal reflexes involving the kidney and bladder after spinal cord injury; 3)



conditions favoring functionally effective reinnervation of the urinary bladder by foreign nerves; 4) factors associated with the specificity of reinnervation and regeneration after injury of sympathetic preganglionic neurons; 5) changes in utilization of amino acids and associated modification in cytoskeletal protein synthesis by motoneuron cell bodies after injury of their axons; 6) modifications of the projections into the spinal cord of thin

afferent fibers after injury of dorsal roots and associated alterations in functional properties of neurons in laminae I and II; and, 7) modifications in the distribution of chemical markers for primary afferent fibers such as peptides in the spinal gray matter after injury of ascending spinal pathways.

#### **Publications Resulting from This Research**

None reported.

### **[111] Repair of Injured Nervous Tissue with Foreign Grafts**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—The purpose of this project is to investigate the repair of injured nervous tissue with foreign grafts.

**Results**—Peripheral nerve fibers of adult rats can regenerate into silicone tubes wherein they re-form a new nerve segment. We used an electron microscopical histochemical technique to determine whether barrier function to macromolecules developed in the blood vessels and perineurial-like cells would appear. Nerve segments permanently enclosed in or free of tubes for 3 months were examined with the barrier tracer, horseradish peroxidase (HRP). All segments contained remyelinated axons, blood vessels, and perineurial-like cells which divided the nerve into mini-compartments. Most vessels were excluded from the endoneurium of the mini-compartments. Intravenously-injected HRP, which was retained by vessels in normal nerves, leaked out of them. The regenerated endothelial cells stained for alkaline phosphatase activity were equivalent to that seen in HPR-impermeable vessels of the normal nerve. The perineurial barrier was analyzed in

segments soaked in HRP *in situ*. HRP entered only the superficial fascicles of segments formed in permanent tubes because of a dense layer of collagen that developed between the nerve and inner tube lining. The collagen layer was absent after early tube removal, and HRP penetrated the deeper perineurial-like sheaths and entered the endoneurium where it spread around the nerve fibers.

These results demonstrated that neither blood nor perineurial permeability barriers exist in nerves reconstructed in tubes. We have continued to investigate the immunological factors that determine allograft immunogenicity. Ganglia grafts were transplanted between congenic B10 mice that differ only in Class I (K region) or Class II (I region) histocompatibility antigens. Frozen sections revealed that the grafts were rejected. The lack of an I region stimulus does not lead to allograft tolerance since K region disparities alone can elicit rejection.

#### **Publications Resulting from This Research**

None reported.

## [112] Rapid Neuronal and Glial Changes in the Spinal Cord Following Injury

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*Sponsor: Paralyzed Veterans of America*

**Purpose**—Recently it has been demonstrated that functionally ineffective pathways exist in the uninjured spinal cord and other areas of the central nervous system. One approach to achieving functional restitution of the injured spinal cord is by growth of new axon pathways through the damaged regions. An alternate approach, being studied by this group, is by activation of functionally latent axonal pathways and synapses. The purpose of this project is to assess morphological and electrophysiological changes of the phrenic nucleus following spinal cord injury in rats.

**Progress**—Following hemisection at the C-2 or C-7 levels, the cytoarchitecture of the ipsilateral phrenic nucleus was examined. Seven days following C-2 hemisection, the number of double and multiple synapses was increased in the phrenic nucleus, although the mean length and percentage of

dendrodendritic appositions did not change. Following C-7 hemisection there was no change in the number of double or multiple synapses or in the mean length or percentage of dendrodendritic appositions. Additionally, immediately following C-2 hemisection, phrenic nerve activity showed a significant increase.

**Future Plans**—Future experiments will include a quantitative analysis of crossed phrenic nerve activity. The morphological changes and physiological results will be compared to determine if there is a relationship between the morphological changes of the phrenic nucleus and the functional recovery found immediately following hemisection.

### **Publications Resulting from This Research**

None reported.

## [113] Electric Field Distribution in the Injured Spinal Cord. Part 1: Electric Field Mapping

**Joel B. Myklebust, PE, PhD; Talat Khan, PhD; Thomas Swiontek, PhD**

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*Sponsor: VA Rehabilitation Research and Development Service (Project #B423-RA)*

**Purpose**—These studies are designed to augment ongoing evaluations of electrical stimulation for neural regrowth in the injured spinal cord. Experiments are designed to evaluate the distribution of current in the spinal cord for various electrode configurations and to design appropriate implant systems for experimental use.

**Progress**—Progress has been made in several areas. The experimental apparatus has been upgraded to enable improved data collection. A model spinal cord has been developed using gelatin to facilitate the development of the electrode system. Mapping

studies have been performed in the gelatin model and *in vivo* in the cat spinal cord. Additionally, implantable systems have been designed and fabricated to provide DC and pulse stimulation of the cat spinal cord for periods of up to 6 months. Furthermore, a system to evaluate weight-bearing in the injured cats is being designed.

Because the potentials to be measured are routinely in the 1-2 mV range, the recordings are subject to artifact from noise and electrode drift. Consequently, an ON/OFF switch was included with the DC stimulator, and the potentials are recorded as changes in potential from turning the



stimulator from "off" to "on." Positioning systems used in moving and placing the microelectrodes have been improved. All three recording electrodes have fine adjustment with 3 degrees-of-freedom. Although the cats were suspended from the vertebral bodies, not all movement of the spinal cord was prevented. The standard reference electrode was thought to be causing damage to the spinal cord and injury currents were observed. A reference electrode was constructed using silastic tubing filled with 0.9 percent saline with cotton wadding at the end. The impedance of the reference electrode was measured to be 170 kohms. The end of the silastic tubing rested on the surface of the spinal cord and allowed for small movement of the spinal cord. This did not cause any injury to the spinal cord.

A wick electrode was designed for the purpose of mapping the surface of the spinal cord and for measuring injury potentials. The recording electrode consisted of a microelectrode holder and glass filament. The microelectrode holder and upper portion of the recording electrode was filled with 3M KCl, and the lower portion was filled with 0.9 percent saline. Cotton wadding was placed in the middle of the filament to separate the two solutions. The impedance was measured to be 70 ohms. This design allowed surface potentials to be easily recorded with no injury to the spinal cord.

A 4 to 6 cm laminectomy was performed routinely from T2-T12. Potential measurements were taken on the surface of the spinal cord and

in-depth around the electrodes while stimulation was applied. Both DC and AC stimulators were used. Stimulation was applied to the dorsal surface, and in other studies, between electrodes on the dorsal (D) and ventral (V) aspects of the cord. The positions of two measurement electrodes were kept constant at either end of the laminectomy, while the other was used to map the spinal cord. Potential changes were only seen in the moving microelectrode when the system was stable. Currents of 10-50 $\mu$ A were used. No difference in potential distribution was observed with current magnitude. The distribution with the pulse stimulator was similar to that obtained with the DC unit. Dorsal-ventral stimulation confined a larger portion of the current to the spinal cord than did dorsal stimulation.

A gelatin model of the spinal cord was developed to facilitate electrode design. The model consists of the appropriate amounts of Knox unflavored gelatin and 0.9 percent saline to achieve the desired resistivity. The gelatin model was molded into a cylindrical shape by refrigeration in 5 mm diameter straws 7 to 10 cm in length. Experiments were done in which a DC stimulator (10.3 $\mu$ A) was applied and the model mapped. The surface of the model and the depth around the electrodes were mapped. The results show the same characteristic curves that were attained from the cat experiments.

#### **Publications Resulting from This Research**

None reported.

### **[114] Electric Field Distribution in the Injured Spinal Cord. Part 2: Neuroanatomical Studies**

**Talat Khan, PhD; Joel B. Myklebust, PE, PhD; Michael Dauzvardis, PhD**  
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Clement J. Zablocki VA Medical Center, Milwaukee, WI 53295

**Sponsor:** VA Rehabilitation Research and Development Service (Project #B423-RA)

**Purpose**—The project evaluated the electric field potential in the experimentally-injured spinal cord resulting from applied electric currents. In addition, the influence of these currents on the regrowth of injured nerve fibers was measured by electrophysiological and neuroanatomical correlates. Ten cats weighing from 2 to 2.5 kg were anesthetized with an intramuscular injection of ketamine and xylazine. A laminectomy was performed at T8-T10

and the spinal cord was completely transected at the T9 level. In 5 animals, a small electric field was applied through an implantable stimulator (TRAXON™) with the anode 1 cm rostral and the cathode 1 cm caudal to the lesion. The electrodes were placed epidurally on the dorsal surface of the spinal cord. The control group consisted of 5 animals that received complete spinal transections with no stimulation. All animals received extensive



post-operative care in compliance with American Association for Accreditation of Laboratory Animal Care (AAALAC) guidelines.

**Progress**—Electrophysiological recordings showed good responses in all animals when stimulation and recording was performed either above or below the lesion. However, these responses were absent in the control group when stimulation and recording was done across the lesion. While 3 animals in the stimulated group showed responses starting at 3 ms and peaking at 4 ms, it is possible that current from the stimulating electrode spread to the fibers present in or at the other side of the lesion. Histologically, longitudinal serial sections of the lesion site stained with silver protargol showed cyst formation at the site of transection. Many axons were found within the cysts and most of these appeared to form a continuity across the lesion. These nerve fibers seem to be arising from dorsal root and they appear to be occupying the void left by degenerating nerve tissue. In the control group, many axons were present at the outer edge of the lesion, but few were found within or crossing the lesion. Large cyst and abundant scar tissue were present in the control

group. Apparently dorsal stimulation of the injured spinal cord promotes growth of dorsal root fibers into the lesion site.

**Future Plans**—Our field measurement studies have shown that when both stimulation electrodes are placed dorsally, only 35 percent of the current is measured on the surface at the dorsal column and 5 percent in depth. When the stimulating electrodes are placed in a dorsal-ventral (D-V) arrangement, the measured field intensities are much higher (70 percent on the surface and 50 percent in depth). We are planning our future experiments with D-V configuration of the stimulating electrodes.

#### Publications Resulting from This Research

**Injury Potential Distribution in Cat Spinal Cord.** Myklebust J, Khan T, Swiontek T, *Transactions of the Bioelectric Repair and Growth Society*, 8, 1988.

**Electrical Stimulation in the Treatment of Experimental Traumatic Spinal Cord Injury.** Khan T, Myklebust J, *International Symposium on Biomagnetism, Magnetobiology and Magnetotherapy*, Newport, RI, 1989.

**Improved Micturition with Direct Current Stimulation of the Spinal Cord in the Spinal Cat.** Khan T, Dauzvardis M, Walter J, Robinson CJ, *Soc Neurosci Abstr* 15:630, 1989.

## D. Rehabilitation

### [115] Development and Evaluation of Computer-Aided Instruction for SCI Patients: A Pilot Study

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Sponsor: VA Rehabilitation Research and Development Service (Pilot Project #B983-PA)

**Purpose**—The purpose of this pilot project is to develop and evaluate the first of a series of computer-aided instruction (CAI) tutorials directed at the learning needs of the newly spinal cord injured population. The CAI will instruct and test a critical area of learning before a patient is discharged into the community from the Spinal Cord Injury (SCI) Center. By the end of the funding period, the pilot project will have developed a CAI tutorial on autonomic dysreflexia compatible with a variety of computer interfaces to allow for indepen-

dent computer use by all SCI patients regardless of functional ability. After development of the tutorial, 30 SCI patients will be involved in the evaluation of this program. The Autonomic Dysreflexia tutorial will serve as a model for the development of the remaining topics in the series of CAI for SCI patients.

Spinal cord injury rehabilitation involves learning new ways of doing everyday tasks, psychosocial adaptation, and the acquisition of new knowledge. For SCI patients, independence in the learning



environment is strongly desired. The computer, with its capability to allow any individual to access it regardless of the level of disability, lends itself to providing that independence for individuals with spinal cord injury.

Several advantages for using CAI to teach about spinal cord injury would be: 1) consistent information given to each patient and family member while in the hospital; and, 2) the potential for the patients to do in-home instruction of attendants after discharge from the hospital. Forty to forty-four percent of high quadriplegic patients hire an attendant. Many of these individuals hire and train two or more attendants each year over a lifetime of 30 to 50 years. Most attendants have not had any SCI training or experience as there are no formal programs in existence. Therefore, the quadriplegic must do all his/her own training and educating. Teaching with CAI may be a desirable option for these individuals. A secondary gain may result if patients become sufficiently comfortable learning/testing with the computer to move on to using computer assistance for other educational/vocational and avocational pursuits.

**Progress**—The tutorial on autonomic dysreflexia was designed and developed by a team of content experts: an instructional designer, a graphic designer, and a programmer. The Macintosh computer was chosen due to its graphic capabilities, user-friendly interface, and availability in many SCI Centers and homes. HyperCard was chosen as the authoring tool due to the ease of development for non-technical staff, interactive branching capabili-

ties, and Apple Computer Inc. and other third party support in terms of future development.

The tutorial has been designed for independent operation by any SCI patient regardless of the level of disability through the use of a standard keyboard and mouse, trackball, or Personics HeadMaster optical pointer. Secondary audiences for the program include family, attendants, medical staff, and students. Professional graphics, animations, and voice feedback have been incorporated in the program in order to make learning interesting and motivational. Content information is presented on individual cards with questions following each section. A post-test is given after the learner has completed the tutorial, to evaluate retention and application of the material. Student record-keeping and data collection features are embedded in the program.

**Results**—To date, the tutorial has been developed and is in the process of review by content experts before beginning formal evaluations. Starting in late October, the tutorial was evaluated by 30 patients from the Spinal Cord Injury Center. Based on the results of these evaluations, final changes will be made and the tutorial will be available for distribution on floppy disk to patient homes, clinics, hospitals, schools, and other facilities.

#### **Publications Resulting from This Research**

**Development and Evaluation of Computer-Aided Instruction for SCI Patients.** Lloyd E, Hammel J, Holloway K, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 308-309, 1989.

## **[116] Rehabilitation of Reproductive Function in Paraplegic Males**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B299-3RA)

**Purpose**—Restoration of normal sexual function in male spinal cord injured (SCI) patients is an important facet of their own personal rehabilitation, and is a significant challenge to rehabilitation medicine as well. Although advances in technology, medical care, and public awareness/concern have caused

improvements in the overall rehabilitation of SCI patients, sexual rehabilitation in all of its ramifications, until recently, has received little emphasis for these patients. The ability to function sexually at or near normal ability is a prime concern and objective of the SCI patient as well as of this research.



**Progress**—Previous funding has permitted development and refinement of the technique of rectal probe electrostimulation (RPE) to assist in the production of erection and seminal emission in unanesthetized SCI patients with minimal intact lower-level sensorium. The use of this technique has permitted the identification of injury-level range among SCI patients who might best benefit from RPE. Collection of semen has become sufficiently routine that a related phase of work, namely that of semen evaluation and studies directed toward improvement of motility, has been another major area of interest.

More recent funding has been directed at the miniaturization and packaging of instrumentation with the aim of producing an instrument suitable for professional use and subsequent commercialization. This has required enormous attention to details of electrical safety as well as to ease of use for trained professionals. Two devices have emerged: one using current from electrical mains, the other a battery-operated device. Both utilize state-of-the-art electronic safety features, and the latter has been designed with the possibility of home use by patient and spouse.

**Results**—Particular progress has occurred during the past year in the development, construction, and implementation of computerized circuitry in the RPE device which permits automatic rhythmic current delivery in the patterns found most appropriate for erection and emission. In the past, these stimulus

patterns had to be produced by manual dial manipulation. Not only is progressively increasing current delivery possible, with appropriate pre-set current cutoffs to meet specific patient requirements, but two other options can also be superimposed. One permits a temporary repeat cycling at any given rhythmic stimulus intensity, and the other permits the resumption of normal current cycling from that particular level rather than beginning an entirely new stimulus cycle.

**Implications**—For those patients whose sensorium does not permit current delivery up to the established safe maximum, this capability for hovering at a submaximum level is more effective for initiating erection and emission than the more standard routine of patterned, steadily increasing, rhythmic current delivery toward the maximum permitted value. Using a computer-generated stimulus pattern also improves the repeatability of stimulus delivery. This is an important consideration in providing comparison of results both among and within patients. In turn, this is essential to acquire a sufficiently large database for analysis of the efficacy of this procedure as a possible addition to the armamentarium of rehabilitation medicine.

#### **Publications Resulting from This Research**

**Infertility in the Paraplegic Male.** Perkash I, Martin DE, in *Current Therapy of Infertility*, C-R. Garcia, L. Mastroianni, R.D. Amelar, L. Dulsin (Eds.), Toronto: B.C. Decker, Inc., 1988.

### **[117] Wheelchair Graded Exercise Test for Patients with Lower Limb Disabilities**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B398-RA); Vaughan Chapter of the Paralyzed Veterans of America

**Purpose**—The primary purpose of this 2-year study is to develop improved methods for the objective evaluation of the cardiorespiratory health and fitness of the spinal cord injured (SCI) and other patients with lower limb disabilities. Information garnered from the application of these evaluation procedures will provide baseline data useful in

judging the effectiveness of patient rehabilitation and cardiorespiratory training programs and in charting any progressive deterioration of health resulting from disability-imposed inactivity.

The three objectives of this research are to: 1) establish standardized maximal and submaximal wheelchair graded exercise tests to accurately mea-



sure the cardiorespiratory fitness of patients who are restricted to the manual wheelchair; 2) evaluate the sensitivity of the testing system for detecting abnormal cardiovascular and pulmonary responses to exercise stress in SCI and other persons with lower limb disabilities; and, 3) compare data resulting from the experimental wheelchair testing protocol with data obtained from conventional arm crank ergometry.

**Progress**—Last year we outlined the procedures employed in the calibration of an experimental wheelchair ergometer called the Wheelchair Aerobic Fitness Trainer (WAFT). Modifications to the magnetic eddy-current brakes and the determination of the power output requirements for the various stages of the wheelchair-graded exercise testing were completed. During testing, a new video display provided the subjects with constant feedback, including: right and left wheelchair wheel speeds and a sprite (heading indicator) that points in the direction of wheelchair travel.

Forty-three male subjects (17 to 69 years old) with tetraplegia, paraplegia, amputations, and other lower limb disabilities were grouped according to age (<30 years, 30-49 years, and >49 years). All subjects had been using the manual wheelchair as their primary mode of mobility for at least 3 months. After giving their informed consent, each subject completed one continuous and one discontinuous maximal graded exercise stress test on the WAFT and one continuous test on the arm crank (AC) ergometer.

Stages were 3 minutes with power output increments of 16 watts per stage for the AC and 7 minutes for the WAFT. To test the validity of employing the new wheelchair ergometer for graded exercise testing, a preliminary analysis, using regression and analysis of variance (ANOVA) procedures, was completed on the data from 28 subjects who completed one continuous graded exercise test on the WAFT and one on the AC.

Within age groups, WAFT versus AC peak measures for pulmonary ventilation (VE), oxygen uptake ( $\text{VO}_2$ ), and heart rate (HR) were not signifi-

cant ( $p > 0.05$ ). Peak VE, HR, and  $\text{VO}_2$  were significantly correlated in each age group ( $p < 0.02$  for all ANOVA). These initial findings support the validity of the WAFT for testing the cardiorespiratory fitness of a heterogeneous sample of persons whose mobility is restricted to the manual wheelchair.

Seven persons with suspected coronary artery disease (CAD) who, because of their lower limb disabilities, were unable to safely complete a treadmill or bicycle ergometer test completed one WAFT and one AC continuous graded exercise test. The exertional stress resulting from the WAFT and AC tests was sufficient to elicit clinical signs and symptoms of coronary artery disease. At this time, there is not enough data to draw any conclusions regarding the viability of employing the WAFT in wheelchair graded exercise tests for the detection of CAD.

### Publications Resulting from This Research

**Design Considerations for the Wheelchair Aerobic Fitness Trainer.** Robinson CJ, Langbein WE, Kynast LT, Kampschoer CJ, Wurster RD, Dunlap B, Cramer R, *IEEE/Engineering in Medicine and Biology, 9th Annual Conference*, Boston MA, 1987.

**Development of a Wheelchair Aerobic Fitness Trainer.** Langbein WE, Kynast L, Robinson CJ, Wurster RD, Bolam JM, Dunlap B, in *Proceedings of the 9th Annual RESNA Conference*, San Jose, CA, 331-332, 1987.

**Development of a Wheelchair Aerobic Fitness Trainer for Individuals with Spinal Cord Injury.** Langbein WE, Kynast L, Robinson CJ, Wurster RD, Bolam JM, Dunlap B, *American Paraplegia Society*, Las Vegas, NE, 1987.

**Interface Considerations for the Wheelchair Aerobic Fitness Trainer.** Robinson CJ, Langbein WE, Kampschoer CJ, Kynast LT, *IEEE/Engineering in Medicine and Biology, 10th Annual Conference*, New Orleans, LA, 1988.

**Speed-Torque Calibration of the MAGTURBO and Wheelchair Aerobic Fitness Trainer.** Langbein WE, Robinson CJ, Kynast LT, *IEEE/Engineering in Medicine and Biology, 11th Annual Conference*, Seattle, WA (in press).

**Interactive Video Games and Real Time Displays for the Wheelchair Aerobic Fitness Trainer.** Flaherty BP, Robinson CJ, Langbein WE, *IEEE/Engineering in Medicine and Biology, 11th Annual Conference*, Seattle, WA (in press).

**Validation of a New Wheelchair Ergometer for Graded Exercise Testing of Persons with Lower Limb Disabilities.** Langbein WE, Robinson CJ, Hwang MH, Reid C, *American Heart Association 62nd Scientific Sessions—Medical Research, Nursing Research*, New Orleans, LA (in press).



## [118] Interactive Videodisk Training for Self-Care Skills

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B451-RA)

**Purpose**—Between one-third and one-half of people with spinal cord injuries are rehospitalized in any given follow-up year. The average annual cost for each rehospitalization can range from \$6,700, if surgery is not required, to \$20,000, if surgery is required. The incidence of rehospitalization due to preventable complications can be decreased with appropriate instruction in self-care skills. Such instruction can also hasten people's progress toward adaptation to their disabilities and personal independence.

Traditional methods of health-care education such as personalized instruction by a health-care professional, self-instruction from written or audio-visual materials, participation in learning groups, or interaction with other disabled persons are often ineffective. The success of such programs may be influenced by factors such as the person's psychosocial, economic or educational status; the extent of involvement by health-care professionals; and the instructional material or methods. Although some of these factors can be controlled and improved, others cannot.

Accordingly, health-care institutions are faced with the difficult problem of teaching valuable skills to people with diverse socioeconomic backgrounds, attitudes, and skills, using staff who may have little time to teach them. We believe that this problem may be resolved by augmenting traditional education programs with interactive learning technologies such as computer-assisted instruction (CAI) or interactive-videodisk instruction (IVI) which have several advantages as adjuncts to traditional educational methods.

People with diverse socioeconomic and educational backgrounds can learn at their own pace. The novelty of interacting with a computer may provide motivation for learning. CAI or IVI may also be more effective than personalized instruction for teaching difficult or emotion-laden subjects, since they are impersonal and non-threatening. Interactive learning technologies also free staff to give personalized instruction to people who need it.

**Progress**—We have developed a menu-driven authoring package for IBM-compatible personal computers that allows someone with marginal computer skills to develop highly interactive instructional material. The authoring system provides the user with interfaces to routines for creating graphics, computer-generated speech, menus, two- or four-alternative questions, and routines for controlling commercial videodisk players. It also provides the user with the ability to establish the sequence of instructional material and create complex scenarios with feedback to the student. We have developed an instructional series on skin care and will soon be testing its efficacy as an adjunct to traditional instructional methods for self-care skills in a population of persons with spinal cord injuries.

### Publications Resulting from This Research

**Independent Living for Paralyzed Veterans.** Kafka R, Mask J, Hooker E, Johnson P, Trimble J, *Paraplegia News* 18-19, 1987.

**Interactive Videodisk Training for Self-Care Skills.** Trimble J, Nemchausky B, Johnson P, Kafka R, Hooker E, Amel E, in *Proceedings of the 1st Annual Conference of Spinal Cord Psychologists and Social Workers*, Las Vegas, NV, 14, 1987.



## [119] Exercise Hemodynamics of Quadriplegics: A Pilot Study

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Sponsor: VA Rehabilitation Research and Development Service (Pilot Project #B954-PA)

**Purpose**—The purpose of this pilot project was to assess the acute central and peripheral hemodynamic adjustments of spinal cord injured (SCI) quadriplegics to graded submaximal and maximal arm-crank exercise (ACE) and to prolonged bouts of submaximal ACE in two postures (sitting and supine) representing two different orthostatic loads. Specifically, this study was designed to: 1) separate the hemodynamic effects of posture and exercise; 2) assess the effects of postural change on exercise capacity; 3) study physiologic mechanisms which may improve blood flow to active muscles in quadriplegics during arm exercise; and, 4) determine the extent to which postural stress may contribute to hypokinetic circulation in quadriplegic subjects during arm exercise.

**Methodology**—Fifteen healthy SCI quadriplegics (levels C5-C8, mean age 35 years) with good orthostatic tolerance served as subjects for this project. Each subject performed five tests: 1) 45-minute supine rest, followed by 45-minute sitting rest; 2) two graded exercise tests to fatigue (one in sitting posture and one in supine posture); and, 3) two prolonged (50-minute) exercise tests at 70 percent maximal oxygen uptake. Physiologic determinations were made with open-circuit spirometry, impedance cardiography and plethysmography, ECG, and auscultation.

**Results**—*Rest Test.* Acute postural change from supine to upright sitting produced a 31 percent decrease in cardiac output, 65 percent decrease in stroke volume, 15 percent decrease in thoracic fluid volume, 25 percent increase in heart rate, and 18 percent increase in calf-segment fluid volume. Forty-five minutes of additional rest in the upright sitting posture induced 11 percent and 18 percent further decreases in cardiac output and stroke volume, respectively. These results indicate that

central hemodynamic function in quadriplegics is compromised by prolonged sitting in the upright posture.

*Maximal Exercise Tests.* Compared with the sitting posture, maximal arm-crank exercise testing in the supine posture produced significantly higher mean peak levels of power output (by 32 percent, +11 W), oxygen uptake (by 22 percent, +0.16 L/min), cardiac output (by 15 percent, +1.1 L/min), stroke volume (by 11 percent, +6 ml/bt), myocardial contractility (as indicated by decreased PEP/LVET ratio) (by 36 percent, -0.15), and pulmonary ventilation (by 16 percent, +8 L/min). These results showed that during maximal voluntary arm-crank exercise the supine posture produced beneficial central hemodynamic adjustments that are associated with superior exercise performance as indicated by the higher peak levels of several metabolic and cardiovascular parameters. Supine posture may also allow improved pulmonary mechanics and biomechanical stability of the shoulder girdle which may aid in arm-crank exercise performance.

*Prolonged Submaximal Exercise Tests.* Fifty minutes of arm-cranking at equal relative exercise intensities (70 percent  $\dot{V}O_2$  peak) were performed in each posture. Compared with the upright sitting tests, subjects were able to perform supine arm-crank exercise at a higher mean power output, oxygen uptake, cardiac output, and stroke volume, with equivalent subjective ratings of perceived exertion. These results suggest that the supine posture allows higher levels of arm exercise with the same relative difficulty compared with upright sitting.

These results support the original hypothesis that central hemodynamic performance is strongly dependent upon posture in SCI quadriplegics. Absence of lower-extremity venous pooling, increased mechanical stability of the upper body, and improved pulmonary mechanics probably contribute to



the improved arm exercise performance and central hemodynamic responses observed in the supine posture.

**Future Plans/Implications**—In SCI quadriplegics, supine ACE may be a more appropriate mode than upright ACE for cardiac exercise stress testing and general aerobic cardiovascular training, based upon

the greater metabolic and cardiopulmonary responses elicited during supine ACE. Methods to increase the active muscle mass during exercise also deserve attention.

#### **Publications Resulting from This Research**

None reported.

### **[120] Effect of Exercise on Upper Extremity Recovery Following Quadriplegia**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B320-2RA)

**Purpose**—Patients with cervical spinal cord injury commonly recover at least one segmental level of spinal cord function following their injury, and maximizing this recovery of arm and hand function can greatly enhance independence. Standard therapy for this weakness includes range-of-motion exercises to maintain joint mobility, strengthening exercises to reverse muscle atrophy and functional training to restore functional use. Therapy may also include electrical stimulation to weak muscles. This nerve stimulation is clearly of benefit later in the recovery process in reversing muscle disuse atrophy. However, other recovery mechanisms are active during the early post-injury period, including resolution of upper motoneuron weakness, resolution of neurapraxia, and motor axon sprouting with reinnervation of denervated muscle fibers. The effects of nerve electrical stimulation on these early neural mechanisms are not known. This study examines the time-course of strength recovery in upper extremity muscle groups following cervical spinal cord injury.

**Methodology**—One weak muscle group is selected for nerve electrical stimulation for 4 weeks, in addition to standard treatments. Another comparably weak muscle group in the opposite extremity receives only standard treatments. The rate and final level of strength recovery are compared for the electrically stimulated and the nonstimulated muscles.

**Results/Future Plans**—To date, 5 patients have completed the nerve electrical stimulation protocol. This data is being analyzed and additional subjects are being recruited. This study will document whether early nerve stimulation is beneficial in promoting recovery of strength. The long-term objective is to maximize functional recovery by directing appropriate therapies toward active recovery mechanisms.

#### **Publications Resulting from This Research**

None reported.

### **[121] Evaluation of Spasms in Spinal Cord Injury**

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**Sponsor:** VA Rehabilitation Research and Development Service (Pilot Project #B953-PA)

**Purpose**—The objective of this pilot grant was to develop a portable device capable of objectively

monitoring spasms using surface electromyograms (EMGs), without interfering with routine activities.



The data analysis system was to have the capability of measuring both the frequency and severity of spasms, while recording patient activities and filtering noise.

**Methodology/Preliminary Results**—The prototype hardware has been built and tested. The current emphasis is on the completion of the software to download and analyze the acquired data. We will continue refinement of the hardware, emphasizing miniaturization of the hardware package, as well as further refinement of the software.

The hardware consists of two modules. The analog system consists of modules of four instrumentation amplifiers with selectable gains from one to 1,000. The common mode rejection rate is 105 dB. Each module has a 12-bit A/D converter capable of sampling at 30 kHz. Because of our emphasis on miniaturization, the amplifier modules are being implemented as hybrid circuits. The final size of each module will be approximately  $2 \times 2 \frac{1}{2}$  inches. They are configured to be "stackable," so that at least eight channels are available in the portable system.

The digital system is built around the Hitachi HD641016 microprocessor with its extensive data analysis capabilities and fast speed. This 16-bit processor has, built in, 1K random access memory (RAM), four channels of direct memory access control (DMAC), two serial channels, two 16-bit timers, and dynamic memory control in an 84-pin programmable logic device (PLD) package. It has

two low-power consumption modes (Sleep and System Stop) which make it ideal for this application. Because the processor has only recently become available, the lack of system and development support necessitated some delay in the finalization of our design. Because of our concern with miniaturization, it was decided to use dynamically-programmable logic arrays from Xilinx for buffering and interfacing requirements. This has allowed a significant savings of space for the digital system (a reduction in chip count of 10-12). In addition, because the device is dynamically programmable, the flexibility of the system is significantly enhanced.

The system is presently implemented with 256 B of battery backed-up static RAM expandable to 1 MB, and 1 MB of dynamic RAM (expandable to at least 4 MB). In addition, we have incorporated a serial link for communication with larger computer systems, a 2-line video display, and a 12-button keypad used for input/output (I/O).

The entire system is powered by a single lithium battery (Gould V/P6/1400) which has a capacity of 1400 milliamp hours. This battery is 3 inches wide  $\times$  3.7 inches long  $\times$  0.18 inch thick, and weighs from 1 to 2 ounces. This smaller battery further contributes to the miniaturization of the unit and improves clinical utility.

#### **Publications Resulting from This Research**

None to date.

### **[122] Electroejaculation of Spinal Cord Injured Males with Emphasis on Improvement of Fertility and Increasing Pregnancy Rates**

**Dana A. Ohl, MD; Edward J. McGuire, MD; Stephen W.J. Seager, DVM; John F. Randolph, MD**  
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**Sponsor:** *Eastern Paralyzed Veterans Association*

**Purpose**—The purpose of this study is to: continue to study the applicability of electroejaculation of spinal injured and other neurologically impaired anejaculatory males; improve fertility in patients undergoing electroejaculation; determine the effect of urologic management on fertility; determine the role of intrauterine insemination, *in vitro* fertilization, and gamete intrafallopian transfer in achieving

pregnancy; and, improve the safety of the electroejaculation machine with the ultimate goal of producing a patient-operated home-use model.

**Progress**—In the area of safety of electroejaculation: no rectal injury occurred during monitoring by anoscopy; autonomic dysreflexia was noted in almost all patients (pharmacologic agents



and their benefits were studied); no complications were noted during general anesthesia; and one exacerbation of multiple sclerosis (MS) was noted with no known cause.

With regard to fertility: when comparing the level of injury and type of bladder management to fertility, paraplegics on intermittent catheterization did best; compared to sperm motility, antibiotics had little effect on infection; and, low incidence of aberrations were noted in hormone levels with an elevated follicle-stimulating hormone indicating infertility. Immunologic infertility was not found to be significant, and the studies on semen antibodies are forthcoming. Genital duct obstruction was surgically treated and compared with success rate. As to the effect of anesthesia on fertility, no differences were found between the types of anesthesia and the success noted.

The following methods to improve fertility were studied: adrenergic agents (no increased success

noted); clomiphene citrate (testosterone level sperm motility was affected in a positive way); and changing bladder management to increase fertility and rate of success.

Methods of improving pregnancy rates were studied. Inseminations were timed to best increase chances for success, but there have been no definitive findings to date. Research is continuing on the role in *in vitro* fertilization increasing chances for patients with low sperm counts; sperm processing technique to increase density and motility.

**Preliminary Results**—Research is inconclusive on a sperm penetration assay and a protocol has been adopted and is beginning to be incorporated into this project.

#### **Publications Resulting from This Research**

None reported.

### **[123] Evaluation of Virginia Regional Spinal Cord Injury System Follow-up Care**

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The Virginia Regional Spinal Cord Injury Center, Department of Orthopaedics,  
University of Virginia Medical Center, Charlottesville, VA 22908

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The purpose of this study is to evaluate the follow-up care provided to patients in the Virginia Regional Spinal Cord Injury System (VRSCIS). In the VRSCIS, follow-up care is delivered through three centers to accommodate patients from different geographic areas. Patients may be recalled to clinics at Woodrow Wilson Rehabilitation Center (WWRC), the University of Virginia Medical Center, or to an outreach clinic at Abingdon in Southwest Virginia. In addition, patients may receive a home visit from the WWRC project staff at one and two years after discharge, and at least an annual phone call thereafter.

**Progress**—A total of 446 clients in the VRSCIS who met specified criteria were identified as eligible for inclusion in the study. A representative sample of 200 clients, stratified by geographic region, was randomly selected.

Eligible subjects have been contacted by letter inviting their participation in the study. To date, approximately 70 subjects have been visited and data collection completed. The majority of these interviews were conducted in the subjects' homes. Data collection instruments focus on attendance at follow-up appointments and identification of problems, both individual and those inherent in the system.

**Preliminary Results**—From the interviews completed to date, we are able to identify some problem areas. It is becoming clear that there are deficiencies in communication, education, and training, as well as a lack of funds, all of which affect the quality of our subjects' lives.

**Future Plans**—During the remaining year of the grant, interviews will be conducted with the remain-



ing subjects, and the data will be analyzed and interpreted.

**Publications Resulting from This Research**  
None reported.

## **[124] Influence of Age on Rehabilitation Outcome of Persons with Spinal Cord Injury**

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*Sponsor: National Institute on Disability and Rehabilitation Research*

**Purpose**—As the median age of the U.S. population has increased, special attention is now being given to the health care needs of older persons. Even though most people with spinal cord injury (SCI) are relatively young, the health care needs of the subpopulation of older people with SCI may vary enough from their younger counterparts to suggest a need for alternative treatment modalities.

The purpose of this study is twofold: Phase I will examine the influence of age at the time of SCI on various demographic, process-oriented, and short-term outcome factors; Phase II will examine the longer-term impact on the health care delivery system of an aging population with SCI.

**Methodology**—All patients enrolled in the National SCI database will be included in this study. During Phase I, all patients will be divided into six age groups in 15-year intervals. Demographic, process-oriented, and short-term outcome factors will be compared for each age group, either by calculating the percentage of patients with each factor in each age group and then using the Chi-square test, or by calculating the arithmetic mean for each variable in each age group and then using the Student's-*t* test. Multivariate techniques such as analysis of variance, multiple linear, and logistic regression will be used to control for the possible confounding effects of appropriate co-variables such as neurologic level and extent of lesion.

Phase II will be a cross-sectional study comparing current age with outcomes during the current

follow-up year. The data will be analyzed in essentially the same manner as in Phase I.

**Preliminary Results**—The Phase I data set has been created and includes 12,418 patients. Preliminary findings show that patients in the oldest age group are most likely to be white females with motor functional quadriplegia whose injuries resulted from falls. More than one-third were widowed, slightly over one-half were high school graduates, and very few were still employed in the competitive labor market at the time of their injury. These findings were all highly statistically significant ( $p < 0.0001$ ). There was also a statistically significant decrease in both the mean days from injury to system admission, and the mean total days hospitalized for patients in the oldest age group relative to all other age groups ( $p < 0.001$ ). Patients in the oldest age group were also far more likely to be discharged to nursing homes and to be ventilator dependent at discharge than their younger counterparts ( $p < 0.0001$ ). In addition, patients in this age group are the least likely to improve neurologically. Not surprisingly, few patients are employed 2 years post-injury.

**Future Plans**—All Phase I activities will be completed during 1990 and Phase II activities will be initiated.

**Publications Resulting from This Research**  
None reported.

## [125] Aging in Relation to Spinal Cord Injury

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Marcus J. Fuhrer, PhD; Wayne G. Alfred, MA; David Cardus, MD; Rebecca A. Clearman, MD;  
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The Institute for Rehabilitation and Research, Houston, TX 77030

*Sponsor: National Institute on Disability and Rehabilitation Research*

**Purpose**—Under the auspices of the Rehabilitation Research and Training Center in Community-Oriented Services for Persons with Spinal Cord Injury, a study is being conducted on the age-related effects and age-related changes in persons with spinal cord injury. The study is based upon a  $2 \times 2 \times 2$  prospective, longitudinal design that will involve 100 participants. The three independent variables are: 1) duration of injury; 2) age when injured; and, 3) measurement of Occasion 1 versus Occasion 2. Three years will intervene between the two measurement occasions. Dependent variables are being assessed in six different life domains (physical well-being, psychological well-being, social integration, independence, productivity, and economic self-sufficiency) and on five moderating factors (social support, health beliefs and practices, environmental supports, perceived control, and mobility). Threats to physical well-being that were documented include bacteriuria, kidney or bladder calculi, renal insufficiency, pulmonary insufficiency, coronary heart disease, hypertension, spinal arthritis, heterotopic ossification, neuromuscular pain or progressive fatigability, lipid abnormalities, and pressure sores. The psychological well-being of participants will be compared with norms for the general population in terms of life satisfaction, depression, and perceived psychological stress.

**Methodology/Progress**—Participants are chosen on a random basis from a cohort of more than 600 persons with spinal cord injury who reside in a 13-county area in southeast Texas that includes the cities of Houston and Galveston. Following a home visit that includes an interview and completion of multiple self-administered instruments, participants undergo a day-long assessment at The Institute for Rehabilitation and Research that includes a physical examination, clinical laboratory assessments, X-rays, a renal scan, and provocative cardiopulmonary evaluation.

**Future Plans/Implications**—Results of this study will contribute to the identification of risk factors for a number of the age-related problems of persons with spinal cord injury, and to the anticipation of the service needs that emerge as these persons grow older. It is expected that the first wave of data acquisition will be completed within the first quarter of 1990.

### **Publications Resulting from This Research**

None reported.

## [126] Life Status Study of Persons with Spinal Cord Injury

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The Institute for Rehabilitation and Research, Houston, TX 77030

*Sponsor: National Institute on Disability and Rehabilitation Research*

**Purpose**—Under the auspices of the Rehabilitation Research and Training Center in Community-Oriented Services for Persons with Spinal Cord Injury,

this study is being conducted of the life status and service needs of persons with long-term injury of the spinal cord. Life status is being assessed in six



domains: physical well-being, psychological well-being, social integration, independence, productivity, and economic self-sufficiency. Variance in each life domain is being explored as a function of individual difference variables particular to spinal cord injury (e.g., level and duration of injury to the spinal cord) and variables that apply to the general population (e.g., educational attainment and gender). Measures are also being obtained on five variables that are posited to moderate the relationship between the individual difference variables and the life domains. The moderating variables are social support, health beliefs and practices, environmental supports, perceived control of one's life, and mobility. Where possible, measures have been chosen for which norms are available for the general population so that comparisons can be made.

**Methodology/Progress**—A cohort has been established of persons with spinal cord injury who reside in a 13-county area in southeast Texas that includes the cities of Houston and Galveston. A probability sample of 140 persons is being drawn from the cohort which currently numbers more than 600 individuals. Following a home visit that includes an interview and completion of multiple self-administered instruments, participants undergo a day-long assessment at The Institute for Rehabilitation and Research that includes a physical examination, clinical laboratory assessments, X-rays, a renal scan,

and provocative cardiopulmonary evaluation.

Threats to physical well-being to be documented include bacteriuria, kidney or bladder calculi, renal insufficiency, pulmonary insufficiency, coronary heart disease, hypertension, spinal arthritis, heterotopic ossification, neuromuscular pain or progressive fatigability, lipid abnormalities, and pressure sores. The psychological well-being of participants will be compared with norms for the general population in terms of life satisfaction, depression, and perceived psychological stress. Other comparative data concerning social integration, functional independence, productivity, and economic self-sufficiency should contribute to the knowledge base necessary to anticipate the service needs of persons with long-term spinal cord injury.

**Future Plans/Implications**—This study is based upon a representative sample from a cross-section of persons with long-term spinal cord injury rather than a convenience sample of persons known to a particular service program. Consequently, reasonable estimates can be made of the prevalence of various problems and service needs of persons with long-term spinal cord injury. It is expected that data acquisition will be completed within the first quarter of 1990.

#### **Publications Resulting from This Research**

None reported.

### **[127] Long-Term Follow-up of Assistive Equipment Needs of Persons with Spinal Cord Injury**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Our research objectives are as follows: 1) obtain reliable follow-up information on several aspects of equipment utilization by persons with spinal cord injury; 2) conduct a professional assessment of the adequacy with which equipment needs of the particular persons with SCI are being met; and 3) provide recommendations for meeting current equipment needs. In addition, data will be collected to document the incidence with which the neurological level of spinal cord injury changes as

the person ages. Such changes, if existent, would have obvious implications for changing equipment needs.

In the past year we have: 1) revised data collection instruments and procedures based upon the results of pilot-testing the use of proposed instruments and procedures; 2) begun collecting desired information about the patient's equipment history during the home visit; 3) adopted a schedule for processing information about the patient so that



sufficient time is available to review the results of the various evaluations and to prepare summary recommendations regarding the patient's equipment; 4) entered the data for 91 subjects into a computerized data base; and, 5) compiled a summary of the data for all 91 subjects.

**Methodology**—A section of the structured home interview is devoted to assistive equipment. Interviewees indicate the types of equipment currently being used, as well as equipment that was provided or obtained previously, but which is no longer being used. The interviewer documents the physical appearance of questionable equipment by taking Polaroid photographs. The following items are specifically addressed in this study: sliding board, shower-commode chair, tub bench/chair, bedside commode seat, elevated commode seat, grab bars, hospital bed and rails, transfer aids such as bed loops, trapeze and swivel bars, mobile arm supports, hand splints, wheelchair controls, environmental controls, braces, walkers, crutches, canes, stall bars, wheelchairs, wheelchair accessories, and cushions. Obviously, some subjects will have little or no need for such equipment and others will have a need for several of them.

A sample of the study group interviewed at home are invited to come to TIRR for a more complete assessment. During the day at TIRR, a project physician conducts a neurological examination to document the current motor level and sensory level of function. That diagnostic classifica-

tion is being used, along with information from a personal interview by a physical therapist, to reach professional judgments about the appropriateness of each item of equipment. Opinions regarding satisfaction/dissatisfaction with the equipment is also solicited by the physical therapist. Results of this assessment are used to prepare recommendations for meeting current equipment needs of the subject. These recommendations are discussed with each subject during the scheduled follow-up conference to clarify the merit of the recommendations and to share information with the participant that they may value.

The subjects will be classified into four groups on the basis of the motor level of function determined in the neurological examination that is part of Project R-1. The four levels will be: 1) C1 through C6; 2) C7-T1; 3) T2-T10; and, 4) T11-S5. For those patients who received their initial rehabilitation at TIRR, we will review the medical records to obtain documentation of the neurological level of function specified at discharge from the inpatient rehabilitation program, as well as the list of equipment prescribed for the patient at that time. This information will be used to determine if the neurological level changed in the intervening years and to compare equipment utilization then with utilization now.

#### **Publications Resulting from This Research**

None reported.

## **[128] Neuromuscular Plasticity: Functional Recovery**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—Our purpose is to continue to evaluate neuromuscular plasticity as related to functional recovery after spinalization. A major objective of the project is to study, *in vivo*, the motor output capacity of the adult spinal cat by examining selected kinematic, kinetic, and electromyographic (EMG) parameters in the hindlimb.

**Results**—It has been demonstrated that the adult spinal cat has the capability to execute effective locomotion of the hindlimbs, fully supporting their weight while walking on a treadmill. It has also been shown that although training of the hindlimb is not essential in achieving locomotor output at very slow treadmill speeds, it does enhance the capability to



walk at faster speeds. By examining a group of spinal cats that were trained to stand stationary, it was found that this form of postural therapy was detrimental to locomotor performance; i.e., the cats could not walk, or walked only very slowly, on the treadmill. Major deficits in this "standing therapy" group were found in the flexors, as evidenced by EMG of the tibialis anterior.

#### Publications Resulting from This Research

**Differential Kinetics of Fast and Slow Ankle Extensors During the Pay Shake in the Cat.** Fowler EG, Gregor RJ, Roy RR, *Exp Neurol* 99:219-224, 1988.

**Mechanical Output of Cat Soleus During Treadmill Locomotion: In Vivo Versus In Situ Characteristics.** Gregor RJ, Roy RR, Whiting WC, Lovely RG, Hodgson JA, Edgerton VR, *J Biomech* 21:721-732, 1988.

### [129] Movement Deficits Following Spinal Cord Lesions

**Charles J. Vierck, Jr.**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—Motor disorders have long been known to follow damage to the dorsal columns. However, following extensive postoperative training, the only enduring deficits are those involving the grasping and manipulation of objects with the fingers. These results have indicated that the dorsal columns provide specialized sensory information that is critical to the execution of the precise finger movements involved in active touch. As a source of feedback to motor cortex, the dorsal columns may provide information that is critical for digital fractionation, involving precisely timed and directed sequences of movement of individual digits.

Fine movements of the hands have been an exception to the recovery that can result from training after injury; however, training procedures are critically important in providing the full oppor-

tunity for recovery. The stepwise shaping procedures for the finger movement tasks are appropriate to test the limits of functional plasticity of the spinal cord following well-defined damage.

A major goal of this work is to provide information of direct relevance to clinical neurology and neurosurgery. A better understanding of spinal tract function is fundamental to accurate diagnosis of CNS pathology affecting the somatosensory system.

#### Publications Resulting from This Research

**Motor Capacities and Deficiencies After Interruption of the Dorsal Spinal Columns in Primates.** Vierck CJ, Cooper BY, Leonard CM, in *Effects of Injury on Trigeminal and Spinal Somatosensory Systems*, 419-428, New York: Alan R. Liss, Inc., 1987.

### [130] Adaptive Plasticity in the Spinal Stretch Reflex

**Jonathan R. Wolpaw**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—The H-reflex of the spinal cord was used to approach therapeutic strategies for spasticity and other variants of reflex function because these results may furnish a new therapeutic approach to spasticity, as well as other manifestations of abnormal reflex function. Spinal reflex amplitude in one leg of several monkeys had been increased or decreased by conditioning. The goal was to compare

the physiological parameters and anatomical characteristics of the conditioned and unconditioned sides of the spinal cord. It was demonstrated that conditioning did produce persistent changes in the cord ("memory" traces). Motoneurons and their Ia afferents have been labeled with horseradish peroxidase to define their somatic and dendritic morphology and connections. The goal now is to

determine if conditioning causes change at the Ia synapse or in the motoneuron itself.

#### Publications Resulting from This Research

**Jendrassik Maneuver Facilitates Soleus H-Reflex Without Change in Average Soleus Motoneuron Pool Membrane Potential.** Dowman R, Wolpaw JR, *Exp Neurol* 101:288-302, 1988.

**Operant Conditioning of Primate Spinal Reflexes: Effects on Cortical SEPs.** Wolpaw JR, Dowman R, *Electroencephalogr Clin Neurophysiol* 69:398-401, 1988.

**Retrograde Transport of the Lectin Phaseolus Vulgaris Leucoagglutinin (PHA-L) by Rat Spinal Motoneurons.** Lee CL, McFarland DJ, Wolpaw JR, *Neurosci Lett* 86:133-138, 1988.

**Spinal Stretch Reflex and Cortical Evoked Potential Amplitudes Versus Muscle Stretch Amplitude in the Monkey Arm.** Wolpaw JR, Dowman R, *Electroencephalogr Clin Neurophysiol* 69:394-397, 1988.

### [131] Effects of Daily Activities on the Cardiovascular Response in Wheelchair Users with a Spinal Cord Lesion

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**Sponsor:** Programme on Medical Technology, The Free University

**Purpose**—Fifty subjects with a spinal cord lesion and using a hand-propelled wheelchair are being studied with respect to their daily physical activities and corresponding heart rate. The results will be related to their maximum work capacity. Assistive devices used by the subjects will be evaluated with respect to the physical load.

**Methodology**—Subjects are monitored during one complete day with respect to their momentary heart rate and activities. Special attention is being paid to physical activities in relation to the wheelchair and other assistive devices.

Subsequently, the group (n = 50) will be studied in the laboratory during a number of standard tasks, in which a number of general assistive devices will be evaluated in terms of physical stress. Also, a

maximum effort test will be performed on a computer-controlled wheelchair ergometer. Thus, maximum work capacity and wheelchair propulsion technique (torque, power, timing) will be determined.

**Progress**—This study started in April 1989. During the first months, instruments were developed and tested. Ten subjects have been followed during an ordinary day. Activities were registered and heart rate was monitored.

**Future Plans**—This study will be completed in August 1990.

#### Publications Resulting from This Research

None reported.

### [132] Adjustment to Spinal Cord Injury: A Qualitative View

**Jessie W. Drew, RN, MS**

University of Rochester School of Nursing, Rochester, NY 14642

**Sponsor:** American Association of Spinal Cord Injury Nurses

**Purpose**—The purpose of this research was to investigate the process and outcome of adjustment to spinal cord injury (SCI) from the individual's point of view. Adjustment is defined as a process of modifying, adapting or altering individual behaviors. Adjustment is also viewed as a transactional

process, with changes in the environment and the social system within the environment. Adjustment can be conceptualized as both a process and an outcome, both of which change over time. What emerges as central to the processes and outcomes of adjustment, based on the experience of the SCI



individual, is a sense of the individual's ability to partially overcome or transcend the injury. The central question in this research is: What are the processes and outcomes of adjustment within one to five years of injury from the point of view of the individual with a spinal cord injury?

**Progress/Preliminary Results**—Data collection has been completed. Fifty-eight subjects made up the study which involved facilities in New York, Maine, and Florida. Information on the background of each subject was compiled in table form. The data set contained fewer women than projected (8). Mean total age for the group was 27.7 years and the number of quadriplegics versus paraplegics in the study closely resembles national averages. Inter-rater reliability will be evaluated using the Barthel Scale. Other reliability and consistency tests will be applied

to various aspects of the study to achieve the best possible results. Final results should be available shortly.

**Future Plans/Implications**—The nature of the injury and the long-term needs of these individuals requires advanced knowledge and skills in clinical practice. Understanding how individuals adjust to SCI is necessary in the development of practice guidelines for nurses. This disability presents a challenge to nursing to deliver effective care during all phases of this experience: in the acute situation, during rehabilitation, when individuals face the complications of the disability, and as a consequence of the natural process of aging.

#### **Publications Resulting from This Research**

None reported.

### **[133] Qualitative Analysis of Patients' Perspective of a Spinal Cord Injury Unit**

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**Sponsor:** *American Association of Spinal Cord Injury Nurses*

**Purpose**—Overall, the purpose of this study is to explore and describe the subculture of a spinal cord injury (SCI) unit from the perspective of a patient. Ten research questions were delineated which focus on the interactive processes between the patients and staff, patients and environment, and patients and the rehabilitation program, as follows: 1) What is the nature of patient-staff interaction? 2) What staff behaviors are helpful to patients? 3) What staff behaviors are problematic for patients? 4) What are the problems confronted by patients on a spinal cord injury unit? 5) How do patients cope with the unit environment? 6) What is the process of patient socialization to the ward milieu? 7) What are the behaviors of patients on the SCI unit? 8) What are the patient goals and how do patients gauge progress? 9) What do patients see as obstacles to rehabilitation? and, 10) What do patients see as facilitative to rehabilitation?

**Progress**—The study is in its data analysis phase of implementation. Data collection was initiated on 7/11/88 and completed 11/3/88. Plans are underway to present the preliminary findings to the staff, and the patients and families who participated in the study. This will enhance the validity and reliability of the data, in that the additional data and comments collected will be incorporated into the final presentation.

**Future Plans/Implications**—This study is significant because it offers a new perspective for viewing a spinal cord injury unit. By vicariously experiencing SCI rehabilitation, health care workers will better understand patients' responses to treatment. The major goal is to generate a theoretical model that explains patients' attitudes, beliefs, and behavior on an SCI unit. This model will provide a framework for developing improved treatment programs and

rehabilitation nursing strategies which optimize the therapeutic benefits of the SCI inpatient milieu. Lastly, this exploratory study of the subculture on a SCI unit allows for the discovery of relevant research topics related to spinal cord injuries and SCI nursing practice.

#### Publications Resulting from This Research

**Reorganization of Nursing Service Delivery to Maximize Rehabilitation.** Nelson A, Goltry P, Kelley B, *J SCI Nurs* 4(1), 1987.

**Normalization: The Missing Link in Spinal Cord Injury Rehabilitation.** Nelson A, *J SCI Nurs* 4(1), 1987.

### [134] Effects of Inspiratory Muscle Training in Quadriplegics

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Edward Hines, Jr., VA Hospital, Hines, IL 60141

**Sponsor:** *American Association of Spinal Cord Injury Nurses*

**Purpose**—This study will test the health-related effects of four months of inspiratory muscle training in a healthy group of quadriplegic persons with spinal cord lesions between C4 and C8. Health-related effects will be evaluated with respect to the following variables: inspiratory and expiratory muscle strength, respiratory muscle endurance, inspiratory and expiratory capacity, quality of life, respiratory symptoms, and energy level.

**Progress**—Equipment and laboratory facilities have been acquired and organized. Data collection forms have been developed. The project nurse, fully trained in independent data collection, is actively evaluating patients for the study. There are nine

subjects in the study, which is proceeding as scheduled.

**Future Plans/Implications**—This study is directly relevant to persons with spinal cord injuries between C4 and C8. Inspiratory muscle training may improve their health by increasing the strength and endurance of their inspiratory muscles. This may allow spinal cord injured persons to take deeper breaths and mobilize secretions with ease. Increased strength and endurance may be particularly beneficial during episodes of respiratory tract infections.

#### Publications Resulting from This Research

None reported.

### [135] Interpersonal Behavior and Adjustment of Persons with Spinal Cord Injury

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**Sponsor:** *American Association of Spinal Cord Injury Psychologists and Social Workers*

**Purpose**—The primary objective of this study is to determine the impact of personal assertiveness on adjustment following spinal cord injury (SCI). By establishing a clear and significant link between patient interpersonal behavior and adjustment, interventions which improve and augment patient interpersonal skills will be empirically justified. This will accent current psychological services to those with SCI.

The major goal of this project is to establish the direct impact of personal assertiveness on the fol-

lowing psychosocial and health variables: depressive behaviors, psychosocial functioning, the number of days spent in hospitalization, the number and severity ratings of decubitus ulcers experienced by a patient, and, the number of urinary tract infections.

The second goal of this project is to systematically examine variables that could possibly moderate the assertiveness-adjustment relationship, including the following: social support, age of the patient, patient's race, time since injury, and the level and type of lesion.



**Progress/Preliminary Results**—There are no results available at this time.

**Implications**—Persons who have SCI are often in situations in which they must rely on effective interpersonal communication. An assertive person with SCI would be better equipped to deal with interpersonal and social situations routinely encountered by those with spinal cord injuries. Therefore, an assertive person with SCI should be more capable of intimate communication with significant others, defending oneself assertively in the face of inappropriate demands and discrimination, and initiating

and guiding interaction with health care and social service organizations. A person who has the interpersonal skills to handle these situations would be able to maximize the beneficial aspects of these social systems. This would be evident in higher levels of adjustment on psychosocial and health variables.

#### **Publications Resulting from This Research**

**Life Stress and Psychological Adjustment to Spinal Cord Injury.** Frank RG, Elliott T, *Arch Phys Med Rehabil* 68:344-347, 1987.

**Adjustment to Spinal Cord Injury: A Review of Empirical and Nonempirical Studies.** Frank RG, Van Valin P, Elliott T, *J Rehabil* 53(4):43-48, 1987.

### **[136] Survival Following Spinal Cord Injury: A Prospective Approach**

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Department of Psychology, University of Minnesota, Minneapolis, MN 55414

**Sponsor:** *American Association of Spinal Cord Injury Psychologists and Social Workers*

**Purpose**—The purpose of this study is to investigate the relationship between medical and psychosocial adjustment. Once a cycle is initiated between poor psychosocial adjustment and medical problems, it may be difficult to stop. In addition to the great expenditure of financial resources, there is an immeasurable cost in suffering and loss of human potential. If the life situation continues to spiral downward, it may end in the greatest loss of all, death. In this regard, this study has three principal goals: 1) to compare differences in measures of psychosocial/vocational (PSV) adjustment obtained in 1974 and 1985 between persons surviving their injuries until 1988, and those now deceased. This will replicate the Krause and Crewe (1987) study of survival with an increase in sample size; 2) to identify the relationship between psychosocial/vocational adjustment and the nature of death among deceased subjects; and, 3) to identify personality profiles that co-vary with differences in PSV adjustment on variables found to differentiate between survivor and deceased groups.

**Preliminary Results**—The actual response pattern of a subject closely resembles the predictions made in the initial research proposal. There have been three procedural changes in this project, all designed to improve its quality.

**Future Plans/Implications**—Results of the present study will generate information that will ultimately be useful in developing interventions to break down the cycle between poor adjustment and ultimate death. The comparisons between the survivor and deceased groups will indicate the general nature of the variable related to survival.

#### **Publications Resulting from This Research**

**Prediction of Long-Term Survival Among Persons with Spinal Cord Injury: An 11 Year Prospective Study.** Krause JS, Crewe NM, *Rehabil Psych* 32(4):205-213, 1987.

**Spinal Cord Injury Psychological Aspects.** Crewe NM, Krause JS, in *Rehabilitation Desk Reference*, B. Caplan (Ed.), Rockville, MD: Aspen Publishers, 1987.

## [137] Post-Traumatic Stress Disorder in Spinal Injury Patients

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*Sponsor: American Association of Spinal Cord Injury Psychologists and Social Workers*

**Purpose**—Symptoms of post-traumatic stress disorder (PTSD) are often chronic and disabling, and occur at an alarmingly high incidence in diverse populations of individuals exposed to extreme traumatic stress. The severity of the trauma and extent of resulting disability associated with spinal cord injury (SCI) places patients at risk to develop PTSD symptomatology in a manner characteristic of other traumatized populations. This investigation will have three primary objectives to explore this relationship.

The primary objective of this study is to assess the prevalence of PTSD symptomatology in a population of veteran males with traumatically-induced spinal cord injury; a second is to examine the longitudinal course of symptoms which occur in patients who develop PTSD; and, the third is to examine individual differences that predict, or perhaps influence, the development of PTSD in SCI patients and the duration or chronicity of symptoms which become manifest.

**Progress/Preliminary Results**—Appropriate personnel have been hired to conduct the proposed study, and subjects have completed the protocol without complications arising in the proposed procedure. Findings to date indicate that no patients with

trauma-induced SCI have the complete syndrome of PTSD. In fact, the hallmark anxiety symptoms of intrusive re-experiencing of the accident are notably absent. It has also been observed, based on administration of social support measures, that patients with stable social supports (pre- and post-SCI) are less likely to have psychological distress associated with their injury compared to patients with a more disrupted pattern of interpersonal supports. The target goal of projected subjects has not been reached and the study will be extended until this is accomplished.

**Future Plans/Implications**—The results of this proposed research will define the prevalence and form of post-trauma psychological symptoms that have not been previously assessed in SCI patients. This study should help with the development of a reliable, valid, and longitudinal assessment of PTSD. An identification of risk factors and those especially vulnerable will also be a by-product of the results, which should assist in the identification and treatment of this disorder.

### **Publications Resulting from This Research**

None reported.



# V. Wheelchairs and Powered Vehicles

*For additional information on topics related to this category see also the following Progress Reports: [211].*

## A. General

### [138] Handbike Evaluation

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Biomechanics Research Laboratory, University of Illinois at Urbana-Champaign, Urbana, IL 61801

**Sponsor:** *VA Rehabilitation Research and Development Service*

**Purpose**—The Handbike was developed at the VA Rehabilitation Research and Development Center (RR&DC), Palo Alto, CA, to provide persons with lower limb disabilities the opportunity to enjoy the various benefits of riding a bicycle. The primary purpose of this study is to provide an empirically derived evaluation and description of the operating characteristics of the Handbike. To accomplish this purpose, a three-part design has been adopted.

**Progress**—Part One: *Biomechanical Analysis of Handbike and Rowcycle™ Propulsion*. Four to six individuals with lower limb disabilities, aged 17 to 45 years, with no previous experience in riding the Handbike or Rowcycle™, participated in a series of experiments designed to measure kinematics, moments, and forces on the shoulders, arms, hands, and wrists during the propulsion of the Handbike and Rowcycle™.

Part Two: *A Comparison of the Effectiveness of the Handbike and Rowcycle™ for Improving the Cardiorespiratory Fitness of Lower Limb Disabled Subjects*. Eighteen sedentary individuals with lower limb disabilities, aged 17 to 45 years, were randomly assigned to one of three groups: Handbike Exercise (HbX), Rowcycle™ Exercise (RcX), or Control (C) group. All subjects completed a submaximal and maximal arm-crank ergometer (AC) graded exercise stress test before beginning the conditioning programs. Individualized conditioning programs were based on results of the preconditioning AC test. Subjects in HbX and RcX are presently participating

in an 8-week aerobic exercise program using the Handbike and Rowcycle™. Individuals in group C received Handbike and Rowcycle™ riding instruction, but will not participate in the 8-week aerobic exercise treatment.

The frequency, duration, and intensity of the HbX and RcX subjects' conditioning sessions is being closely monitored. Changes in cardiorespiratory fitness will be evaluated from pre-and post-conditioning AC tests. Also being measured is the degree to which the use of the Handbike and Rowcycle™ affect the attitudes of individuals with lower extremity impairments toward physical activity and/or their perception of the availability of opportunities to participate in coactional recreational activities with the nondisabled.

Part Three: *Energy Cost of Handbike and Rowcycle™ Propulsion*. Eight to 10 individuals with lower limb disabilities, aged 17 to 45 years, with no previous experience in riding the Handbike or Rowcycle™ will participate in experiments designed to determine the energy cost of riding the Handbike and Rowcycle™. Each subject will complete one maximal AC graded exercise test. Following riding skill instruction and riding skill testing, subjects will complete six rides for the purpose of data collection: three on the Handbike and three on the Rowcycle™. Each of the 7-minute rides will be over a preset out-of-doors course. One ride will be at a constant speed of 5 mph, one at a freely chosen speed (FCS), and one at 120 percent of the FCS. Exercising heart rates will be monitored by telemetry, and



expired gases will be collected during the last 90 seconds of each ride.

Parts One and Two will be conducted on the campus of the University of Illinois at Urbana-Champaign and Part Three at the RR&DC. Because we are limited to the use of four experimental devices (two Handbikes and two Rowcycles™), the

three parts of this study are in different stages of completion; i.e., Part One, data analysis; Part Two, final 3 weeks of the conditioning phase; and Part Three, instrumentation and subject recruitment.

#### **Publications Resulting from This Research**

None reported.

### **[139] Development of Wheelchair Standards**

**Robert W. Hussey, MD; Lynn Phillips**

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*Sponsor: VA Rehabilitation Research and Development Service (Project #B228-2RA)*

**Purpose**—During the past 10 years, a committee comprised of wheelchair users, manufacturers, prescribers, third-party payers, and rehabilitation engineers in the United States has been developing a set of standardized test methods and standard methods for disclosure of information for wheelchairs. The rationale for standardized test methods and information disclosure is that it simplifies product evaluation and product comparison. The same principle is used for other products, such as automobiles, water heaters, or gas dryers. Standard methods of disclosure routinely provide comparative information.

Wheelchair manufacturers generally have provided extensive information about their products in the literature they distribute to prescribers and purchasers. However, the information dispensed by one manufacturer is not necessarily directly comparable to that of another. This makes product-by-product comparisons difficult.

The ultimate goal of the standards is to provide a common language for talking about wheelchairs. This language can then be applied to facilitate the manufacturing, distributing, and purchasing processes leading to better product design, better selection, and more appropriate purchases.

**Progress/Standards Under Development**—The four parts of the standards that are being developed deal with general concepts, covering terms and definitions, overall, dimensions, test dummies, and the coefficient of friction of test surfaces. The remainder of the standards specify test methods or standard methods of disclosing information about wheelchair performance as follows:

- Part 1. Determination of Static Stability
- Part 2. Determination of Dynamic Stability of Electrical Wheelchairs
- Part 3. Determination of Effectiveness of Brakes
- Part 4. Determination of Energy Consumption of Electric Wheelchairs
- Part 5. Determination of Overall Dimensions, Weight, and Turning Space
- Part 6. Determination of Speed, Acceleration and Retardation for Electric Wheelchairs
- Part 7. Determination of Seating Dimensions
- Part 8. Fatigue, Static, and Impact Strength Tests for Manual Wheelchairs
- Part 9. Climatic Test for Electric Wheelchairs
- Part 10. Determination of Obstacle-Climbing Ability of Electric Wheelchairs
- Part 11. Test Dummies
- Part 12. Determination of the Coefficient of Friction of Test Surfaces
- Part 13. Deleted
- Part 14. Testing of Power and Control Systems for Electric Wheelchairs
- Part 15. Guidelines for Information Disclosure
- Part 7193. Wheelchair Maximum Overall Dimensions
- Part 6440. Nomenclature Terms and Definitions
- Part 7930. Type Classification Based on Appearance Characteristics

**Progress/Collaborative Standards Development**—A committee organized under the auspices of the Society for Automotive Engineers (SAE) currently is



developing standards for wheelchair restraint systems for automobiles and vans. The U.S. wheelchair standards committee is working cooperatively with the SAE committee to ensure that tie-down systems and other restraint systems adhere to the same general principles for wheelchairs that are being developed under the wheelchair standards effort. A similar effort is occurring at the international level through the International Standards Organization (ISO), where a working group recently has been organized to develop standards for restraint systems. As with the wheelchair standards, this work is being carried out cooperatively with domestic standards

development efforts in the participating countries.

A pilot database is being established to collect and store test results from wheelchair manufacturers. In addition, guidelines are being written for clinicians explaining how the information disclosed through the standards can be used in wheelchair prescription. The third major activity of the VA contract is the completion of the standards themselves.

#### **Publications Resulting from This Research**

None reported.

### **[140] Development of Attendant-Propelled Wheelchairs: Hospital Wheelchair**

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**Sponsor:** *Committee for Research into Equipment for the Disabled, Scottish Home and Health Department*

**Purpose**—The aim of the project was to investigate the problems encountered by people involved in pushing attendant-propelled wheelchairs in medical institutions and produce improved wheelchairs by following a program of research and development and extensive user trials.

**Results**—The results of the development and testing led to the production of a prototype chair which sought to avoid the problems of current hospital chairs. These problems can be divided into two main categories: 1) the difficulties involved in transferring patients into or out of the wheelchair; and, 2) the difficulty of pushing and maneuvering the occupied chair.

The various innovative aspects of the prototype chair are as follows: 1) the footrest lowered onto the ground. This removes the primary cause of difficulties encountered when transferring patients, namely that of getting patients' feet onto or off the footrest. It also makes the chair very stable during transfers; 2) armrests project forward to allow patients to assist themselves as much as possible during transfers; 3) a single footlever applies brakes to both rear wheels simultaneously, the lever being easy to access from the sides and rear of the chair; 4) a new type of push handle was developed from ergonomic studies using a treadmill-based pushing simulator; 5) the

seat can be reclined by up to 22 degrees if required to prevent weak patients from sliding out of the chair seat; and, 6) tests of rolling resistance and the ability of a wheel to ride smoothly over small steps such as carpet edges indicated the need for large diameter wheels and soft tires.

This modular chair can serve a dual function as a ward chair and a transit chair. It has sufficient comfort in terms of seating and posture to permit long periods of sitting but is also suited to making frequent journeys with frequent patient transfers. Trials with these chairs in hospitals found them to be highly favored over current chairs both for transit use and for ward use. The greatest value was in a neurosurgical ward with a high percentage of patients with serious head injuries.

**Future Plans**—A manufacturer is being sought to make the complete chair or to incorporate some of the ideas in existing models.

#### **Publications Resulting from This Research**

**A Technique for the Accurate Measurement of Low Values of Rolling Resistance.** Frank TG, Abel EW, in *Proceedings of the Institution of Mechanical Engineers*, 202(D4):251-255, 1988.

**Measurement of the Turning, Rolling and Obstacle Resistance of Wheelchair Castor Wheels.** Frank TG, Abel EW, *J Biomed Eng* 11(6):462-466, 1989.



## [141] Development of Attendant-Propelled Wheelchairs: Domestic Wheelchair

**T.G. Frank, PhD; E.W. Abel, PhD, CEng, FIMechE**

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*Sponsor: Committee for Research into Equipment for the Disabled, Scottish Home and Health Department*

**Purpose**—The aim of this project was to develop improvements to the domestic attendant-propelled wheelchair. The work concentrated on the chair that is commonly prescribed by the National Health Service in the UK: the model 9L lightweight folding chair which is mainly used outdoors.

**Methodology**—Research into the vibrational characteristics of the wheelchairs was carried out in the laboratory. A track with a bumpy surface was constructed to allow frequent and carefully controlled measurements of vibration in the chair to be made. Accelerometers were attached to various parts of the chair or occupant and connected to a portable data logger. This was small enough to be carried on the experimental chair.

Surveys to establish shortcomings of the current wheelchairs were carried out by visiting private users in their homes and staff in hospitals where domestic chairs were in use. All developments evolved in conjunction with repeated trials by users.

**Results**—The surveys conducted during the project showed that the major problems of the domestic chair are: 1) the chair is too heavy; 2) the front wheels are liable to get caught in gaps between paving slabs; 3) the level of transmitted vibration is too high; 4) downhill travel is intimidating; and, 5) checking tire pressure and using the supplied pump is too difficult. In addition, laboratory studies of pushing suggested that the pushing handles were well-removed from the optimum position.

The vibrational studies demonstrated several ways of reducing the vibration reaching the occupant. The single most effective way of reducing vibration without making major design changes was to upgrade the front wheels. Replacing the standard

wheels, which were 190 mm in diameter and 28 mm wide, with a wheel of the same diameter but with a width of 40 mm, and consequently a tire of much greater volume, reduced the transmitted vibrational energy by a factor of about two. Use of this wheel also removes the problem of the front wheels getting caught in small gaps.

Various designs of dynamic brake, to allow the attendant to control the speed of the chair when going downhill, were assessed. The lever mechanisms included a facility to allow use as a parking brake which had an additional advantage in that the brake could easily be applied to let the attendant stop for rests when pushing uphill. A variety of handle positions was assessed during the brake trials.

The requirement for the domestic chair to be light in weight comes from the need of the user to transport the chair in the trunk of a car. A prototype chair was built that divided into two parts which, being lighter and smaller than the complete chair, made the task of getting the chair into the trunk of a car much easier.

To overcome the problems of tire inflation, adaptations for a bicycle pump were developed that gave easy connection to the valve, allowed the user to take a comfortable stance, and gave an indication when the correct pressure had been reached.

**Future Plans**—Manufacturers are being sought to produce the components developed in these studies. A new contract was granted in September 1989 to develop a lightweight "add-on" power module for the domestic attendant-propelled wheelchair.

### **Publications Resulting from This Research**

None reported.



## [142] Costs and Benefits Associated with Limiting Deep Discharge of Wheelchair Batteries

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**Sponsor:** *The Channel 7 Children's Research Foundation of SA, Inc.*

**Purpose**—It has previously been determined that the major cost of running electric wheelchairs is the expense of replacing batteries. By employing an accurate energy gauge that responds to the approach of deep discharge by causing a significant change in wheelchair characteristics, and then, if this change is ignored, shutting down the wheelchair before damaging deep discharge can occur, we expect to extend battery life to a degree more in line with battery manufacturers' published figures.

Devices are already available that indicate state of battery charge, but in our experience we have found these indicators to be largely ignored by the chair users. It is therefore the purpose of this work to develop a system that cannot easily be ignored, and also does not cause hazardous situations to occur.

**Methodology**—Test wheelchairs were selected from a list of clients who had failed to attain at least 6 months use for battery sets, over a period of 2 years. Each wheelchair was fitted with a controller that had a low voltage sensor incorporated, which: 1) reduced the performance of the wheelchair at a known off-load battery voltage; and, 2) finally cut power to the motors if the condition was deliberately ignored.

At the same time the controller was fitted, new batteries of known capacity were also supplied. The capacity of these batteries was checked periodically. To keep close control over the tests, the user's original chargers were retained, although some of these are obsolete models.

**Progress**—A wheelchair controller with battery level sensing is now available in prototype form. Four wheelchairs have been fitted with these controllers, and are presently in use. More will be fitted as the controllers become available. The ampere-hour capacity of the batteries is being monitored regularly.

Incidental benefits have been: the identification of the most suitable type of gel electrolyte batteries, the development of an acceptance test to be applied to battery purchases, and the identification of the most appropriate charger for these batteries. Regency Park Centre has also developed and is marketing a battery capacity tester that accurately determines the ampere-hour capacity of wheelchair batteries under standard discharge conditions.

### **Publications Resulting from This Research**

**Development of Performance Test Facilities for Electric Wheelchairs at Regency Park Centre.** Hartridge M, Garrett RE, Seeger BR, *TADSEM 87 Proceedings*, 67-71, 1987.

## [143] Quantifying the Benefits and Costs Associated with Implementing International Wheelchair Standards

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**Mark Hartridge, MIE Aust; Barry R. Seeger, PhD**

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**Sponsor:** *The Channel 7 Children's Research Foundation of SA, Inc.*

**Purpose**—The purpose of this study is to compare the total cost of manufacturing and using wheelchairs that are built to comply with the minimum requirements of International Standards, with the costs of wheelchairs that do not meet those require-

ments, over a period representing one year's active use.

**Methodology**—A laboratory has been established to enable wheelchairs to be tested to the existing ISO

7176 Standard. Manual and electric wheelchairs were tested to the Standard. Where necessary, manufacturers upgraded wheelchairs to exceed the Standard's requirements. Samples of wheelchairs before and after upgrading were then subjected to an accelerated life test.

Accurate accounting of all malfunctions, repairs, and downtime was made. Also, any increased production costs incurred in improving the wheelchair design to meet Standards requirements were recorded.

**Progress**—ISO 7176 is at present a 15-part Standard, of which five parts are published in their final form, and most of the remainder are well advanced. Wheelchair failures experienced during our testing

to this Standard were representative of those encountered in real life use, indicating that most tests were realistic.

Testing is continuing and there are positive indications that the higher initial purchase price of a Standards-quality wheelchair may be recovered by lower maintenance and upkeep costs. The testing program has been actively supported by local wheelchair manufacturers and agents, and accreditation of the testing laboratory by the National Association of Testing Authorities (NATA) is being sought.

#### **Publications Resulting from This Research**

**Development of Performance Test Facilities for Electric Wheelchairs at Regency Park Centre.** Hartridge M, Garrett RE, Seeger BR, *TADSEM 87 Proceedings*, 67-71, 1987.

### **[144] Ergonomics of Manual Wheelchair Propulsion**

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Faculty of Human Movement Sciences, The Free University, Amsterdam, The Netherlands

**Sponsor:** *Innovation Research Programme for the Disabled*

**Purpose**—The purpose of this study is to analyze manual wheelchair propulsion from a combined physiological and biomechanical perspective, clarify the reasons for the low mechanical efficiency of handrim wheelchair propulsion, and improve the social range of action for users of hand-propelled wheelchairs.

Our end products will be practical ergonomic guidelines and a predictive fitting model for wheelchair-user interface.

**Methodology**—Studies using different wheelchairs and wheelchair configurations were conducted on a motor drive treadmill and a specially designed computer-controlled wheelchair ergometer with respect to physiology, muscle activity, and kinematics.

By using the ergometer, applied torque and forces on the handrims are being studied in a wide variety of wheelchair configurations. The forces on the seat and backrest are being studied and a 3-D film analysis system is now at our disposal.

**Progress**—A sprint experiment (20-second sprints at different resistance levels) was conducted to determine the short-term (anaerobic) power produc-

tion in handrim wheelchair propulsion. In conjunction with the Technical University, Delft, a dissection study was conducted with respect to the shoulder complex. Data on the insertion/origin of muscles, ligaments, capsule, and bony landmarks of 14 shoulders were gathered with a 3-D measuring device.

**Future Plans**—The role of the shoulder girdle in wheelchair propulsion will be studied with the help of the 3-D kinematic film analysis system, electromyography, and the force-measuring capabilities of the wheelchair ergometer. A segment model is being developed with inverse dynamics.

A fitting model of the wheelchair user interface in handrim wheelchair propulsion will also be studied.

#### **Publications Resulting from This Research**

**The Effect of Rearwheel Camber in Manual Wheelchair Propulsion.** Veeger HEJ, van der Woude LHV, Rozendal RH, *J Rehabil Res Dev* 26(2):37-46, 1989.

**Ergonomics of Manual Wheelchair Propulsion: A Prerequisite for Optimum Wheeling Conditions.** van der Woude LHV, Veeger HEJ, Rozendal RH, *Adapt Phys Act Q* 6:109-132, 1989.



**Manual Wheelchair Propulsion: An Ergonomic Perspective.** van der Woude LHV, Amsterdam: Free University Press, 1989.

**Optimum Cycle Frequency in Handrim Wheelchair Propulsion.** van der Woude LHV, Veeger HEJ, Rozendal RH, *Eur J Appl Physiol* 58:625-632, 1989.

**Seat Height in Handrim Wheelchair Propulsion.** van der Woude LHV, Veeger HEJ, Rozendal RH, Sargeant AJ, *J Rehabil Res Dev* 26(4):31-50, 1989.

**A Computer Controlled Wheelchair Ergometer.** Neising R, Eyskoot F, Kruse R, den Ouden A, Storm J, Veeger HEJ, van der Woude LHV, Snijders CJ, *Biomed Eng Comput* (in press).

**The Effect of Treadmill Belt Velocity on Stroke Technique Parameters in Wheelchair Propulsion.** Veeger HEJ, van der Woude LHV, Rozendal RH, *Scand J Rehabil Med* (in press).

## [145] A Modular Wheelchair Tray for the Severely Physically Disabled

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**Sponsor:** National Health Research and Development Programme

**Purpose**—Our purpose is to develop a modular wheelchair tray which meets the therapeutic and communication goals of the clinician and the personal needs of the user and caregiver. Specific goals are to develop an upgraded modular wheelchair tray that can be partially tilted to various positions or be folded away beside the wheelchair by the caregiver, and to fabricate and assess the performance of the upgraded modular tray.

**Progress**—Development of a second generation modular system has focused on creating hygienic, lightweight tray modules which can be customized to accommodate the client and his or her seating insert, as well as the user's communication device and wheelchair control interface. The first module created to meet these criteria is a basic flat tray. It is a laminate construction consisting of a thin molded Kydex (PVC-acrylic alloy) surface and a stiff polycarbonate honeycomb core.

To cushion the tray and protect any delicate communication device nested in the tray from inadvertent collisions, an integral lip reinforced with

high-density polyethylene is provided. Molded arm-rest mounts with support spacers interface the basic tray to the wheelchair and its user. One basic tray was fabricated and an informal clinical assessment of the serviceability was conducted. Results of the trial are encouraging.

A prototype of the second module, which incorporates a hinged adjustable distal section, has been fabricated. The distal section houses the communication device and is of construction similar to the basic flat tray. The proximal section is also a laminate but does not have a raised lip at its periphery in order to minimize the folded thickness of the tray. Hardware attached to the proximal tray and the wheelchair permits the tray to be folded and stored beside the chair without requiring its removal.

**Future Plans**—Clinical trials are in progress.

**Publications Resulting from This Research**

None reported.

## [146] New Wheelchair Tire Invention

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University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903

**Sponsor:** National Institute on Disability and Rehabilitation Research

**Purpose**—Our aim was to develop a maintenance free wheelchair tire. Maintenance free nonpneumatic tires offer important advantages over pneumatic

tires since there is no need to check and adjust air pressure or worry about a flat or puncture (common inconveniences encountered when using pneumatic



tires). Surveys show that tire repair is the biggest wheelchair maintenance problem.

**Results**—This year, a natural rubber, maintenance free wheelchair tire, similar in weight to a pneumatic tire and tube, was invented at the Rehabilitation Engineering Center (REC). A patent application has been filed.

The design was based on performance requirements that equaled or exceeded those for high pressure pneumatic tires now being used for wheelchairs. The new design is an outcome of a careful study using computer-aided design of tires based on finite element analysis of the stresses in a rubber wheelchair tire under operation.

The work centered on white (i.e., nonmarking) rubbers that in the past have shown poor rolling resistance. New developments related to reinforcing particle bonding and rubber-to-rubber bonding have resulted in a white rubber compound with very good abrasion resistance as well as low hysteresis. This combination of properties will give the new tire very long life while offering low rolling resistance.

In addition, the finite element calculations led to a tire design with very low spring constant on the same order of magnitude as a pneumatic tire. With the low spring constant, the tire gives a comfortable ride since it cushions impact with sidewalk cracks and bumps.

The new tire has been produced in test lots as a gray rubber tire for 24-inch wheels, but can be produced in many colors. It has a similar spring constant to a pneumatic tire which will produce a comfortable ride. The wear resistance of the new tire is at least four times better than a typical wheelchair pneumatic tire, and should last for the life of the chair.

The tire is currently being manufactured and marketed in the U.K. where the original research and development was done in cooperation with the Malaysian Rubber Producers' Research Association. When the tire has been successfully developed in the U.K. market, availability is planned for the U.S.

#### **Publications Resulting from This Research**

None reported.

### **[147] Battery Charger Comparative Evaluation**

**Rob E. Garrett, BTech; Mark Hartridge, MIE Aust; Barry R. Seeger, PhD**

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**Sponsor:** *None listed*

**Purpose**—This research project aims to evaluate the performance of a range of battery chargers and to assess their suitability for charging gel-cell batteries for deep-cycle use.

**Methodology**—The battery chargers we are testing are required for use with 24AH and 36AH 24V gel-cell batteries. Chargers to be evaluated have been divided into two groups: those suitable for 24AH, and those suitable for 36AH batteries. For each group, a reference set of Sonnenschein A200 batteries was initially cycled using a laboratory power supply and discharged using a battery capacity tester. This cycling was repeated until the normal early increase in performance leveled out. Individual chargers were monitored while charging the reference set of batteries, and the energy returned from

the battery during discharge was recorded. The state of the reference batteries was monitored between each charger tested by returning to the laboratory power supply for a number of cycles.

**Progress**—A comprehensive Battery Charger Test Facility has been developed. The system is able to measure, periodically, battery voltage (DC, ripple, and peak), current (DC and ripple), mains voltage, and temperature (charger and ambient), for the entire duration of the charging sequence. Normal variations in mains voltage were found to have a significant effect on the time taken to charge batteries and on the measured results. A Watford AC Voltage Stabilizer, type BEN1H, has been purchased, and the charger performance is currently being measured at 240V, 240V + 3 percent and



240V – 5 percent. These figures ensure that the mains voltage is always within the specified mains limit of 240V + 4 percent and 240V – 6 percent.

**Results**—Results have been obtained on a Technical Components Model BC001 (24V 2.5A), Dimtronics Model SBC 24-4 (24V 4A), Avion Model BC 24/6 SA (24V 6A) and Fortress Scientific GK-BC2410 (24V 6A). Research in this area has clarified the difference between the two main types of sealed maintenance-free batteries: microfiber and gel. The DIN 43539 Part 5 Standard refers to gel-cell batteries in deep cycle usage, e.g., wheelchair requirements. These cells have a tight specification on the charging voltage of  $2.3V \pm 30 \text{ mV/cell}$  at 20 degrees C, which corresponds to a maximum allowable peak voltage of 2.33V/cell or 28V for a normal 24V battery system.

Results measured so far have shown that none of the chargers meet the required specification, with three of the four exceeding the peak voltage and

ripple specification. All three of these chargers use full-wave rectification, with no DC filtering, and returned a significantly higher ratio of energy into the battery to energy returned from the battery (typically 1.4 to 1.9 times compared to 1.2 times for the DC power supply type of charger).

**Implications**—The Dimtronics charger is the only one available that conforms to the peak voltage requirement, and is of the DC type with low ripple. This charger is now being recommended for use with all wheelchairs using gel-cell batteries. The significant additional energy applied to the batteries by the full-wave rectified type of chargers, and the fact that they exceed the maximum peak voltage, suggest that these battery chargers are contributing to the short battery life experienced by wheelchair users at the Regency Park Centre for Young Disabled.

#### **Publications Resulting from This Research**

None reported.

### **[148] Wheelchair Evaluation Based on Standards Drafted by the International Standards Organization (ISO)**

**Micheal D. O'Riain, PhD, PEng; Ray Cheng, BSc, MHSc; Louis Goudreau, BSc, PEng; Gilbert Layeux, Reg Tech; Harold Gay, Reg Tech; Gordon Evans, CET**

The Rehabilitation Centre, Ottawa, Ontario K1H 8M2 Canada

**Sponsor:** *The Royal Ottawa Health Care Group, The Royal Ottawa Hospital*

**Purpose**—The objective of this project is to set up a system to test wheelchairs and powered scooters using standards drafted by the International Standards Organization (ISO). These tests will allow accurate comparisons between different models. The results will enable us to determine which wheelchairs would be purchased, subsidized, etc., and which wheelchairs are exhibiting problems.

**Methodology**—This project involved setting up facilities to perform the following: 1) static stability tests; 2) a determination of dynamic stability; 3) a determination of the efficiency of brakes; 4) a determination of overall dimensions, mass and turning space; 5) a determination of maximum speed and acceleration; 6) a determination of obstacle climbing ability; 7) an assessment of power and control systems; and, 8) the performance of overall engineering evaluation of design and construction.

Equipment has been designed, constructed, and installed to measure the above parameters.

**Progress**—In cooperation with the Assistive Devices Programme (ADP) of the Ministry of Health of Ontario, our testing facilities are presently being used to test powered mobility devices which have recently come on the market. The results of these tests will help in deciding whether or not to place these new devices on ADP's list of approved mobility devices.

Special forms have also been developed to report the results of the tests on wheelchairs.

#### **Publications Resulting from This Research**

None reported.

## [149] Durability and Functionality of Manually-Propelled Wheelchairs

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**Sponsor:** *Research Programme on Quality and Functionality of Assistive Devices, The Free University*

**Purpose**—A survey among a group of 609 users of hand-propelled wheelchairs was conducted. The relationships between user-characteristics (disability, intensity of use), and wheelchair features (brand, type, age) were studied in conjunction with individual areas of complaints and approval. The major purpose of the study was to develop new instruments and methodology for the durability and functionality of wheelchairs.

**Methodology**—The wheelchair users were studied with the help of a telephone questionnaire, a failure diary, an activity diary, and a technical inspection of a subsample of the group ( $n = 5$ ).

Both the telephone questionnaire and the technical inspection were conducted twice, with a 9-month interim. The failure diary was kept during this period. An odometer was mounted to the rear wheel of the wheelchair to determine the distance traversed during the 9-month period.

The sample studied was drawn from central filing systems of two major social insurance corpo-

rations and selected on the age of the wheelchair supplied. Three age groups were studied using wheelchairs provided in 1982, 1983, and 1984.

**Results**—The mechanical status of the majority of wheelchairs is far from ideal and sometimes even dangerous for the user. A regular technical inspection may prevent deterioration of the wheelchair and thus improve the longevity of the wheelchair. Subsequently, discomfort among users may decrease and an economic benefit may result.

The three methods aimed at durability of the wheelchairs generally showed a similar result.

### Publications Resulting from This Research

**Functionality and Durability of Hand-Propelled Wheelchairs.** Roebroek ME, Woude LHV van der, Rozendal RH, in *Wheelchairs: Research, Evaluation and Information*, 117-123, A. Davis and T. Bougie (Eds.), Milano: COMAC BME, 1988.

**Methodology of Consumer Evaluation of Hand-Propelled Wheelchairs.** Roebroek ME, Woude LVH van der, Rozendal RH, Milano: COMAC BME, 1988.

## B. Powered Controllers

### [150] Linear Synchronous Motors for Power Wheelchairs

**Kent R. Davey; David A. Ross; Cris Simpson; Lutz Kynast**

Rehabilitation Research and Development Center, Atlanta VA Medical Center, Decatur, GA 30033

**Sponsor:** *VA Rehabilitation Research and Development Service (Project #B338-3RA)*

**Purpose**—The purpose of this project is to study the application of an axial flux motor drive motor to electric wheelchairs and to design more efficient and reliable wheelchair drives. Present drives employing belt, gear, or pulley couplings suffer from frequent breakdowns and poor efficiency (about 20 percent). Additional goals are to minimize noise generated by the motor, and design a lightweight (about 18 lbs)

motor capable of delivering 35 lb·ft of torque and small enough to fit within the dimensions of a typical wheelchair wheel.

**Methodology**—Based on current research, a promising motor design idea was constructed. This design, coined a Linear Synchronous Motor (LSM) was tested for torque, efficiency, and power output



versus size and weight. The actual prototype constructed fell far short of the project goals, but verified the workability of the initial design idea, given certain modifications in geometry and placement of magnetic materials. The design method was to construct a computer model of the prototype based on test results, use the model to evaluate possible design variations, and then construct another prototype for testing. The process was then repeated until the project goals were met.

Concurrently, a power electronics control circuit and a microprocessor-based controller were developed. Both of these designs evolved with each subsequent motor design, the criterion being that these circuits matched the voltage and current requirements of the motor, and provided current and voltage waveshapes which optimized motor performance.

**Progress**—Five prototypes have been constructed and tested. An efficient power electronics circuit has been developed from an adaptation of a DC-to-DC converter circuit known as a Cuk circuit. The new circuit is a DC-to-AC waveform converter. With the aid of the microprocessor controller, this circuit can drive the motor with an arbitrary AC waveform. The controller's job is to select an AC waveform which maximizes motor efficiency within the parameters of the user's input demands.

This power circuit is now functioning correctly, and a controller based on a new Digital Signal Processing (DSP) chip is being constructed. This new DSP-based controller will allow the implementation of more powerful control algorithms, providing more precise and "intelligent" control of wheelchair motion, as well as efficient motor operation.

**Results**—By proper design of the shape and composition of the motor, we have been able to surpass the goal of 35 lb·ft and achieve the goal of 20 lb·ft per motor. Full testing of the present design is still in progress. Initial results indicate the motor can

achieve about 70 lb·ft of torque. This motor was built with expensive high-energy magnets in order to determine what torque and efficiency benefits could be achieved. The same design, implemented with inexpensive ceramic magnets, may be able to achieve the 35 lb·ft goal.

The torque-to-weight ratio increases as the number of poles is increased. This, however, increases the complexity of the construction. With the aid of a computer program which calculates the saturation of the magnetizable media, we have been able to choose an optimum configuration which seeks a trade-off in construction complexity and minimum torque-to-weight ratio.

**Future Plans/Implications**—A low-cost version of the system using inexpensive ceramic magnets will be constructed and evaluated. A motor will then be chosen as a "best candidate" for wheelchairs. The system will be integrated into a wheelchair power-base and test-driven based on ANSI/RESNA wheelchair standards. Feedback from the subjects will be used to optimize DSP control algorithms which interpret and act on user input demands.

#### Publications Resulting from This Research

- Design and Control of a Curvilinear Synchronous Wheelchair Drive.** Davey K, Bass R, Kelly G, Ross D, in *Proceedings of the 10th Annual RESNA Conference*, San Jose, CA, 547-549, 1987.
- On the Design and Control of Low Speed Fractional Horsepower Synchronous Drive Motors.** Davey K, Kelly G, Ross D, Bass R, *IEEE Trans Magn* 1987.
- On the Design and Control of Low Speed Fractional Horsepower Synchronous Drive Motors.** Davey K, Bass R, Kelly G, Ross D, in *Proceedings of the National Science Council*, Taipei, Republic of China, 11(5):398-410, 1987.
- Analysis and Control of Low Speed Fractional Horsepower Synchronous Drive Motors.** Davey K, Vachtsevanos G, Bass R, Kelly G, Ross D, *IEEE Trans Indus Electron* 35(2):239-244, 1988.
- Development of a High Reliability, High Efficiency Curvilinear Synchronous Wheelchair Drive System.** Davey K, Ross D, Simpson D, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 7-8, 1989.



## [151] Unistik™ Vehicle Controller: Clinical Evaluation

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Sponsor: VA Rehabilitation Research and Development Service (Project #B218-2RA)

**Purpose**—The Unistik™ vehicle controller is an adaptive control system added to the inside of a motor vehicle, which allows a driver to control all movement of the vehicle, using one hand (or other limb) on a joystick. The purpose of this study was to test the efficacy of driving for subjects with various types of disability, emphasizing prediction of driving ability by common clinical methods.

**Methodology**—Twenty-two subjects were recruited and screened, targeting any symptoms of depression, seizure activity, heart arrhythmias, or other contraindications to safe driving. Psychological tests performed included: 1) Mini-Mental Status Examination; 2) Tennessee Self-Concept Scale; 3) Multiple Affect Adjective Check List; 4) Symptom Check List 90-R; and, 5) Motor-Free Visual Perception Test.

The tests were administered, coded, scored, and reviewed by a clinical psychology consultant. Upper extremity examination performed on each subject included: 1) manual muscle testing; 2) strength of neck, shoulder, elbow, wrist, and finger muscles; 3) functional grasp and release (a measure of the distance from the body a subject can grasp and release an object at various shoulder angles); 4) nine-hole peg test (a standardized test which measures the time necessary to insert/remove nine standard pegs in a small pegboard); 5) active range of motion; 6) grip strength; 7) oppositional and appositional grip strength; 8) sensory level to pinprick; 9) joint proprioception; and, 10) stereognosis. A gross evaluation of upper extremity spasticity was performed and recorded in a standardized fashion. A standard vision test and written test covering Washington driving laws were administered.

Initial training took place on a driving range, after the primary and secondary controls were positioned appropriately, and the most effective driving interface was chosen. Special mirrors were installed and adjusted to provide full visibility. The

subject was then instructed in the operation of the vehicle.

When proficiency was attained on the driving range, driver training was moved to city streets, and carried out in the usual manner. After completion of driver training, a standard road test was administered to each driver, identical to the Washington Driver's License Road Test.

**Results/Conclusions**—During the study, the vehicle was driven 8,916 miles and functioned and responded exactly as designed. Mean behind-the-wheel training time was 8.39 hours (SD = 3.53, Range = 5.00 to 20.00). Mean miles traveled during behind-the-wheel training amounted to 50.8 miles (SD = 24.2, Range = 30.3 to 110.0). There was no correlation of hours and miles driven with driving range and road test scores.

For those drivers with good shoulder function, placement of the control boxes was not critical. However, those subjects with very weak or non-functioning shoulder muscles required precise positioning of the controls. Of the 22 subjects who finished the program, 17 progressed to city/residential driving, and 15 had adequate skills to drive the vehicle independently and obtain a Washington driver's license. All but one of the drivers with "passing" scores had driven before the onset of disability. The predictive value of muscle function was not as great as was expected. Shoulder strength, particularly internal rotation, was the only function which correlated with driving ability. Spasticity was not a significant factor in ability to drive. In fact, those with spasticity were better drivers (Pearson correlation coefficient of spasticity scale score with driving test score was +6380,  $\text{sig} < 0.01$ ), not as a function of spasticity, but probably as a function of better shoulder function and pre-injury driving experience of the spinal cord injured individuals. The best predictor of driving ability was driving range performance.



**Implications**—From the results of this study, joystick driving appears to be particularly functional for the traumatic C5 quadriplegic who has driven before the onset of disability. Joystick-controlled driving for these individuals seems to be a viable option for the future.

### Publications Resulting from This Research

**Unistik™ Vehicle Controller: Clinical Evaluation and Prediction of Driving Ability.** Britell C, Arbutina W, Mano A, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 3-4, 1989.

## [152] Ultrasonic Head-Controlled Wheelchair and Interface

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**Sponsor:** VA Rehabilitation Research and Development Center Core Funds; Paralyzed Veterans of America

**Purpose**—The Ultrasonic Head Control Interface (UHCI) is a device designed to provide severely disabled individuals (quadriplegics) with a means of controlling devices such as electric wheelchairs in a socially acceptable and aesthetically pleasing manner.

**Methodology**—Two Polaroid ultrasonic distance-ranging sensors are the basis for a new type of human-machine interface. The sensors emit inaudible high-frequency sound waves which propagate through the air until reflected by an object. A portion of the signal incident on the object, reflected as an echo, is detected by an electronic system. The elapsed time from transmission of the signal to the reception of its echo is proportional to the round-trip distance from the sensor to the object.

Two separated sensors are directed at the user's head. The two resultant distance ranges (one from each sensor to the head), and the fixed distance between the stationary sensors describe a triangle whose vertices are the two sensors and the user's current head position. A geometric relationship allows the offset from the baseline and centerline of the two sensors to be calculated.

This information is then used to map the user's head position onto a two-dimensional control space. The array of distance-ranging sensors can monitor the head position of a severely disabled quadriplegic operator to obtain command-and-control information for the operation of mobility, communication, and robotic devices.

The user tilts his/her head off the vertical axis in a forward/backward or left/right direction. The translation of head-position information into electri-

cal signals can mimic the output of a joystick. Both can be used to control devices to which they are attached (i.e., a wheelchair, communication aid, video game, or robotic arm).

The main advantage of this type of interface is that no mechanical contact between the sensors and the user's head is required, thus effectively separating the user from the device being controlled. The user does not feel confined or "wired-up." Use of the remote sensing ability of the UHCI should result in rehabilitation devices that are socially acceptable and cosmetically pleasing.

**Results**—UHCIs have been installed on two electric wheelchairs. The first, an E&J model 3P equipped with a reclining Recaro seat, is in use in France by a quadriplegic woman. The second is mounted on an Invacare Rolls IV with a Solo Products Power Pack and is being evaluated by spinal cord injury patients at this VA facility.

Both units have been operational since June 1983. User evaluation has been performed with ten quadriplegic individuals. After a short demonstration and training session, they were transferred to the chair; most were able to successfully navigate the chair without any problems. Users stated that they preferred the ultrasonic head control to their chin-controlled joystick wheelchairs. The UHCI has proven to be easy to use. Its intuitive operation requires little focused concentration and thus does not result in user fatigue.

A generalized interface for a robotics application has also been developed. As with the UHCI, the robot user is able to select tasks and control the operation of a mobile robotic arm via head position.



Specifically, the vehicle's navigation path is under the control of the user with its trajectory being "drawn" on a CRT with head motions.

A technical manual documenting the work on the UHCI, including background material, electronic schematics, computer program listings, explanations, and illustrations has been compiled. Its intended purpose is to provide information that allows a technically knowledgeable and adequately equipped engineer to construct a duplicate UHCI and apply it to the control of devices such as powered wheelchairs. This manual has been made available to over 100 investigators worldwide who are considering the UHCI for research or commercialization.

Information on the "Smart Wheelchair" was presented at conferences from 1982 through 1984 and in 1986 at an IEEE Short Course on Rehabilitation Engineering.

### [153] Reliable Electric Wheelchair System Design

**James H. Aylor, PhD; John G. Thacker, PhD**

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**Sponsor:** *National Institute on Disability Rehabilitation Research*

**Purpose**—The objective of the research effort is the application of state-of-the-art engineering techniques to the development of safe and highly-available electric wheelchair systems. Although five steps have been outlined in the development process, the ultimate goal is the development of a prototype of the next generation electric wheelchair. The new design will experience fewer repairs, less downtime, and safer operation.

**Progress**—The research effort is broken into five phases: 1) dependability (measured in terms of reliability, availability, and safety) techniques for "mixed" systems, that is, systems containing both the mechanical and electrical components; 2) analysis of existing wheelchair designs; 3) analysis of new designs; 4) bench prototypes of system components; and, 5) complete wheelchair prototype.

**Preliminary Results**—Results to date include a unique personal computer-based software system especially designed for the dependability analysis of electric wheelchair systems, a fault-tolerant micro-

**Future Plans/Implications**—Funds for production of four commercial prototype units have been received. A solicitation and set of specifications was published. Eureka Laboratories of Sacramento, CA was selected to manufacture these devices. The commercial prototype units were delivered to the VA Rehabilitation Evaluation Unit in Baltimore, MD.

These devices will be evaluated at VA Medical Centers throughout the country. Finally, a decision will be made regarding the prescription of electric wheelchairs using the UHCI technology for appropriate severely disabled veterans.

#### **Publications Resulting from This Research**

See "Results."

processor-based controller, and a fault-tolerant motor drive system.

The dependability analysis software was developed for the average wheelchair system design engineer. The user does not have to be well-versed in dependability analysis or reliable design principles. Models for analysis can be developed from library-based elemental models or novel models can be developed by the sophisticated user and placed in the library. Failure rates for system components can be directly entered and software is included for the calculation of failure rates from failure statistics. Typical failure rate dependencies on both external factors such as aging and use patterns and other system components can be easily incorporated into a model.

An Intel 8088-based multi-microprocessor system has been designed and constructed to be ultimately used as the electronic controller for the wheelchair prototype. The specific configuration is a two-computer system sharing a global memory. Each computer has the ability to provide total motor control independently. An operating system was



developed to support fault-tolerant operation of the system and will provide for the graceful degradation of system operation through the shedding of noncritical tasks such as battery monitoring. Testing of all system components such as the shared memory and the interface hardware is provided.

A fault-tolerant power field-effect transistor (FET)-based circuit has been designed and constructed which will be used as the motor drive elements of the electric wheelchair. The design is based on passive fault-tolerant principles and is capable of tolerating all single-point faults and many multiple faults. Fault detection and location is accomplished using the electronic controller.

**Future Plans**—Activities continue toward the development of the wheelchair prototype. System-level studies are being conducted to determine the optimum configuration for the prototype and the expected improvement in dependability. Software is being developed for the electronic controller and designs for the interfaces between the various components of the system are being developed. In addition, improvements to the software system continue to be made.

#### **Publications Resulting from This Research**

None reported.

### **[154] Research and Development of Wheelchair Design**

**Rafael M. Inigo, PhD**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The purpose of this study is to conduct research in the following areas of wheelchair design: 1) motor analysis and design; 2) digital controllers; and, 3) optical joystick.

**Methodology/Progress**—The type of direct current (DC) motor used in electric wheelchairs (EWC) has not changed in the last 25 to 30 years. It is an armature-controlled permanent magnet DC motor with a conventional commutator controlled by means of a DC-DC converter. In the last 10 years, great advances have been made in other types of motors such as DC brushless, DC disk (pancake), low inertia pm, and AC disk synchronous. These motors show great potential for EWC applications. One of the main advantages is the possibility of eliminating gear trains, which are heavy and have low efficiency.

**Motor Analysis and Design.** We have collected significant information on characteristics and design equations for the types of motors described above. At present we are evaluating the efficiency of some of them experimentally.

**Digital Controllers.** A digital adaptive controller based on the Z-80 microprocessor was implemented and tested. However, both the Z-80 and the host computer used are now obsolete. Due to this,

we are now updating the system by using an IBM-AT host. This is a personal computer that will be used for many years to come and if improved versions become available, the "old" software will still be compatible. We are redesigning (and will implement) an improved digital controller based on the 80C188 CPU using a single card V40 microcomputer. This will improve performance, reliability, and cost compared to the multi-card system previously implemented.

**Optical Joystick.** Conventional joysticks use two potentiometers to produce a variable voltage proportional to the direction of deflection of the lever used to guide the chair. A new joystick using a light-emitting diode and four photodetectors was designed and implemented as part of the new EWC design using the adaptive controller. While keeping the circuit simple and the cost low, the optical joystick produces a more reliable performance because the only motion is mechanical; there are no electric potentiometers. The electric signals are obtained from solid state devices that do not wear, and unless subject to over-voltages, the device should last longer than any other EWC component.

#### **Publications Resulting from This Research**

None reported.



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**[155] Electric Wheelchair Battery Research**

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**James J. Kauzlarich, PhD; James H. Aylor, PhD**

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*Sponsor: National Institute on Disability and Rehabilitation*

**Purpose**—The battery energy storage system is the most limiting factor in powered wheelchair performance. Deep discharge lead-acid wet cell and gel cell batteries are under investigation, and the chargers for the batteries have been investigated as to performance and effect on the batteries. New lighter weight batteries with higher energy densities are being sought for wheelchair use. A version of the lead-acid cell battery that offers much greater cycle life than standard flat plate batteries is called the tubular positive plate lead-acid battery. This battery has been available in Europe for wheelchair applications, but not in the United States. We are working with battery manufacturers to develop improved batteries for wheelchairs, and new developments should result from this activity in a few years.

**Progress**—We are currently in the process of developing a new method for controlling the charger for the battery. Several end-of-charge methods have been implemented in industry with varying degrees of success. A majority of these involve either final voltage determination or voltage slope analysis. If the end-of-charge control is faulty, the battery may be undercharged or overcharged. If a battery is undercharged, the apparent operating time is gradually depleted and the cells become charge-imbalanced. If the battery is overcharged, battery electrolyte is consumed, requiring that pure water be added to the battery frequently, even if it is a maintenance-free battery. Severe overcharging can degrade the battery's active material. The point of view taken for charger control has been that of applying digital microcomputer technology to the

problem. Our initial efforts along this line are to measure the acceleration of the battery voltage time curve and use microcomputer methods to control the end of charge. A microcomputer has been constructed and tested.

**Preliminary Results**—A patent application has been filed for a new invention called "A Rubber Encased Battery Plate." This invention generally relates to the encasement of a battery plate in a porous rubber coating. The invention concerns the problem associated with battery life in that the positive plate of a lead-acid battery is known to shed due to charge/discharge changes in the structure of the active material of the plate. This shedding can considerably reduce the cycle life of the battery. Methods whereby the positive plate is encased in porous tubes or sleeves has resulted in batteries with a much longer life, but the method is expensive and difficult to apply. In the present invention of the REC, an improved life battery is produced when the positive flat plate (negative plates do not shed as easily as positive plates and it is not necessary to encase the negative plate) of a lead-acid battery is coated in a rubber compound that becomes porous by special treatment afterwards. The research to date has established the feasibility of the new invention, and development into controlling the rubber coating thickness and porosity is ongoing. The work to date is still in the prototype stage.

**Publications Resulting from This Research**

None reported.

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**[156] Serial Wheelchair Control Interface Standard**

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**Joseph M. Schauer, BS; Gregg C. Vanderheiden, PhD; David P. Kelso, MS**

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, University of Wisconsin-Madison, Madison, WI 53705

*Sponsor: National Institute on Disability and Rehabilitation Research*

**Purpose**—The development of "intelligent" micro-processor-controlled wheelchairs in the past several

years has made it possible to create more sophisticated control devices. Electronic communication



aids used by non-speaking physically disabled individuals can now potentially be used as wheelchair controls, thus allowing the user to operate both systems from a single control.

However, these devices can only be used as controls if they can be effectively interfaced to the wheelchair. At the present time, intelligent joysticks must be interfaced individually to each model of wheelchair they are to be used with. No interface exists for communication aids, but several aid manufacturers are interested in developing them.

In anticipation of the development of intelligent control systems, Trace Center engineers have begun developing a protocol for a standard connection. As long as both the control and the wheelchair conform to the specifications of the standard, any manufacturer's control device can be used with any manufacturer's wheelchair.

**Methodology**—The standard uses serial ASCII code as the data transmission format for the interface. In addition to defining the format of data transmission, the standard defines a set of specific codes to be sent to achieve particular wheelchair control actions. The standard also sets down electrical

specifications, connector types, and pin assignments. The standard is circulated in draft form to interested parties in the field; their comments are integrated in future revisions.

**Progress**—The Serial Wheelchair Control Interface (SWCI) Standard was discussed in meetings of wheelchair manufacturers, communication aid manufacturers, and researchers at the annual RESNA conferences in 1988 and 1989. A draft version was circulated for comment. The document is distributed through the Trace Center Reprint Service. The draft has also been sent through the RESNA Technical Guidelines Committee.

**Results**—The draft of the proposed standard is to be sent to the International Standards Organization (ISO). Based on comments on the initial draft copies, a final draft will be completed. This final draft will again be sent to RESNA for comment.

#### **Publications Resulting from This Research**

**Serial Interface for Powered Wheelchair Control.** Schauer JM, Vanderheiden GC, Kelso DP, Madison: University of Wisconsin, Trace Research and Development Center, 1988.

### **[157] Development of a Wheelchair Longevity Test**

**Rob E. Garrett, BTech; Mark Hartridge, MIE Aust; Barry R. Seeger, PhD**

Rehabilitation Engineering Division, Regency Park Centre for Young Disabled, Kilkenny, SA 5009 Australia

**Sponsor:** *None listed*

**Purpose**—Standards have been developed to test various aspects of wheelchairs. This work is aimed at developing and evaluating a computer-controlled test for the complete drive mechanism of an electric wheelchair. The joystick is driven, and the chair's response while situated on instrumented rollers, is measured.

**Methodology**—The joystick is controlled by a closed-loop feedback system that uses the ISO 7176 Part 4 Indoor Test Track as the reference input. The control error is monitored as the chair is driven repeatedly around the track. Inertia loads are added to the rollers and test dummies are used in the wheelchair.

**Progress**—Control of the wheelchair joystick has been achieved by using a model radio control system. The transmitter has been modified to accept an analog control signal from the computer, and the remote control receiver is mounted on the chair, along with two servos positioned to control the joystick throughout its normal range. Encoders mounted on the wheelchair test facility rollers have been interfaced to the computer, and software written in Turbo C computes the wheelchair position, displays the position on the screen, and is able to position the joystick. Work is progressing on the closed-loop software.

#### **Publications Resulting from This Research**

**None reported.**

## C. Seating Systems

### [158] Principles of Saddle Design Incorporated into Adaptive Seating for Children with Cerebral Palsy

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**Sponsor:** *Edward Dunlop Foundation*

**Purpose**—The saddle seat will be designed to be used both as a wheelchair seat and as a separate seat in the classroom. This will necessitate an adaptable design that allows the seat to be moved from situation to situation. The design will include the ability to place the seat within a wheelchair frame as well as other bases. It will incorporate a tilting mechanism that will facilitate changing the sitting hip angle so an optimum position can be achieved.

**Methodology**—The seat will be evaluated with four children who require adaptive seating. Two children will have spastic cerebral palsy and two will have athetoid cerebral palsy. The evaluation process will compare the present seating to the saddle seat. Parameters to be evaluated will be: 1) presence or absence of lumbar curve; 2) spinal posture and alignment; 3) hand function/upper limb assessment; 4) head control; and, 5) comfort rating by child.

Items one through four will be rated by qualified therapists utilizing standard motor assessment tools. Item five will be a 5-point rating scale with 1 being "horrible," and 5 being "very comfortable."

**Implications**—A large number of disabled children require adaptive seating. This research and development project has the potential for impacting on a significant number of these children. New approaches to the design of adaptive seating are necessary if the optimum positions are to be found. This study is expected to incorporate therapeutic treatment principles into seating design in order to make a positive impact on seating for children with either moderate or severe cerebral palsy.

#### **Publications Resulting from This Research**

None reported.

### [159] Functional and Clinical Evaluation of the Long- and Short-Term Effects of an Anteriorly-Tipped Seat in Children with Cerebral Palsy

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**Morris Milner, PhD, PEng, CCE; Wallace Lotto, MD, FRCS(C), FACS; Ruth Koheil, DipP&OT, BSc(PT)**  
Hugh MacMillan Medical Centre, Toronto, Ontario M4G 1R8 Canada

**Sponsor:** *National Health Research and Development Programme*

**Purpose**—Two major studies, one related to respiration and swallowing, and the other to the evaluation of the sitting posture, were recently completed.

The purpose of this project is to combine the results of these two studies and observe the effect of an altered sitting position on spinal posture, respiration, and hand/arm function. Twenty-four subjects,

16 with cerebral palsy, and 8 normal children between five and eight years of age will participate in the study.

The goals of this study are to: 1) monitor and record the short-term and long-term effects of a 10-degree forward-inclined chair on respiratory patterns using inductance plethysmography, and on



posture using OMNITRACK to monitor position of C7 in children with cerebral palsy; and, 2) evaluate the short-term and long-term effects of a 10-degree forward-inclined chair on spinal elongation, targeting response abilities, and upper-limb speed and dexterity in children with cerebral palsy.

**Results**—The study is in progress and no conclusions can be made at the present time.

#### **Publications Resulting from This Research**

None reported.

## **[160] Research and Development to Improve Seating Design**

**Kao-Chi Chung, PhD; Clifford E. Brubaker, PhD; Colin A. McLaurin, ScD; Stephen H. Sprigle, PhD; David M. Brienza, MSEE**

University of Virginia Rehabilitation Engineering Center, Charlottesville, VA 22903

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The purpose is to develop a new seating technology utilizing CAD/CAM for the improvement of tissue viability, body positioning, comfort, functional ability and mobility in a wheelchair, and specialized seating. Specific objectives include: 1) study of tissue mechanics and physiology for the design of seating supports; 2) development of CAD/CAM custom seating systems for clinical application; 3) optimization of wheelchair seating and positioning and propulsion; and, 4) information dissemination and technology transfer. The optimal goal is to provide cost-effective devices for the disabled community.

**Progress/Results**—The work in progress and accomplishments are summarized as follows:

*Analytic Modeling of Weightbearing Soft Tissues.* Magnetic resonance imaging (MRI) techniques have been used to quantify biomechanical properties and structure information of buttocks soft tissue in response to externally supportive loads for normal and spinal cord injured (SCI) persons. A nonlinear finite element model of weightbearing tissues has been developed that analyzes and predicts the internal tissue deformation to correlate the results from MRI measurements. Work has continued to characterize the atrophic tissues of SCI and to verify the validation of analytic modeling process.

*Blood Flow and Volume Measurement in the Lower Limbs.* An impedance plethysmograph has been used to study the effects of body positioning on lower limb circulation. The preliminary study

indicated that the blood flow of SCI subjects (particularly for quadriplegics) increased more than the able-bodied as a result of reducing postural stress through raising leg support, tilting, and reclining from an upright seated posture. However, the limb volume decreased less and slower in the SCI as compared to the able-bodied. This suggests that SCI persons can improve limb circulation and reduce limb swelling by altering their seated position and body orientation within wheelchair seating systems.

*Evaluation of Custom Contoured Cushions (CCCs).* An earlier prototype of a CAD/CAM seating system which can measure custom seat contours and fabricate CCCs has been used to study the feasibility of CCCs for different disabled populations. The CCC of a seated individual without severe deformity can be provided in 30 minutes with various foams at a cost of \$5.00 each. A systematic evaluation of twenty chronic SCI persons (C-4/5 to L-3) demonstrated that the CCCs were superior in nearly all aspects of clinical consideration (particularly for pressure relief and posture) to the commercial cushions used by the subjects. The preliminary study of other disabled groups has also been encouraging for the continued development of custom contour seating. Further clinical evaluation will center on cerebral palsy children and geriatric population.

*Design of CAD/CAM Seating Systems.* A computer-aided shape sensor system has been developed using spring suspension for the determination



of both custom seat contour and force distribution at the buttocks-support interface. This semi-automated system allows manual adjustment of the individual sensor elements to prescribe the appropriate contour surface for different disabilities. The formation of contoured surface depends on the spring stiffness. Work is continuing on selection of springs to match various needs (disability, weight, sex, and age) and stiffness of foams. In addition, a Closed-Loop Automated Seating System which uses stepper motors to drive positioning probes and fiber optic pressure sensors has been designed. An adaptive control algorithm has been developed to drive the stepper motors based on the control input of pressure for the formulation of optimal contour surface. Work will continue in the implementation of these CAD/CAM systems for clinical application.

**Wheelchair Propulsion.** A study has been conducted to determine the effects of spinal cord injury, upper limb geometry, seat position, and workload on simulated wheelchair propulsion efficiency and resultant joint moments. Work has also progressed in the development of dynamic modeling for the optimization of propulsion in conjunction with the experimental data of wheelchair simulation.

**Wheelchair Seating and Positioning.** An adjustable fitting and positioning seat in conjunction with the CAD/CAM seating systems has been designed for the development of modular and custom supports for wheelchair users. Work has continued in the study of trunk support, the effects of body

support and positioning on muscle activities, and functional abilities in cerebral palsy children.

**Technology Transfer.** The custom seating technology has been successfully transferred to the South Carolina Rehabilitation Engineering Center for a service delivery program and Pin Dot Products (Chicago, IL), a major manufacturer for specialized seating systems. Further collaboration will aim at the provision of cost-effective seating devices in the disabled community.

#### Publications Resulting from This Research

**The Effect of Postural Stress on Lower Limb Blood Flow in SCI Persons.** Schunkewitz JE, Sprigle SH, Chung KC, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 77-78, 1989.

**A Fiber Optic Force Sensor for Automated Seating Design.** Brienza DM, Brubaker CE, Inigo RM, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 232-233, 1989.

**Material Properties of Soft Tissue in Compression.** Todd BA, Chung KC, Thacker JG, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 73-74, 1989.

**A Test Simulator for Wheelchair Propulsion.** Hughes CJ, Wilson LQ, Weimar WH, Sheth PN, Brubaker CE, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 448-449, 1989.

**The Use of Contoured Foam to Reduce Seat Interface Pressures.** Sprigle SH, Chung KC, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 242-243, 1989.

**UVA Custom Contoured Seating System.** Chung KC, Sprigle SH, Brienza DM, Brubaker CE, McLaurin CA, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 236-237, 1989.

### [161] Research and Development of Assessing Wheelchair Ride Quality

**John G. Thacker, PhD; Clifford E. Brubaker, PhD**

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**Sponsor:** National Institute on Disability and Rehabilitation Research

**Purpose**—A systematic method of evaluating the ride comfort for wheelchairs is needed to provide users with quantitative evaluation data. The ability of components of a wheelchair to affect ride comfort is not well understood, yet many new wheel and tire designs and seating system designs advertise improved ride quality. The data can also be used to establish the feasibility of certain interfaces with

respect to the dynamic aspects of the wheelchair seating suspension.

**Progress**—A review of the literature has shown that the clearest and most reproducible method for evaluating the comfort of ground-based vehicles is the International Standards Organization (ISO) Standard 2631-1978E Guide to the Evaluation of



**Human Exposure to Whole Body Vibration.** A three axes acceleration measuring system donated by PCB Piezotronics, Inc., Depew, NY, coupled with a personal computer data acquisition system is used to measure the accelerations of the seat upon which the rider sits. The wheelchair is rolled over obstacles to produce the seat accelerations. Standard speeds and obstacles are being specified to insure uniformity of results. Data is reduced using fast Fourier transform routines developed at the UVA REC to obtain the root mean square (RMS) accelerations and frequency spectrum of the accelerations.

A 3×7 foot wheelchair treadmill and the standard ISO wheelchair dummy are currently being used as the prime mover and load for manual wheelchair systems. An AT&T 6300 personal computer coupled with a MetraByte Dash 16 data acquisition board are used to collect the acceleration data. The reproducibility of the ride comfort data collecting system with the treadmill test configuration has not yet been established. Software has been written to calculate the means and standard deviations of RMS acceleration data from ten separate runs for at least four different speeds, three bump heights, and two different tires stiffnesses. This

results in 240 separate experiments that evaluate three axes of acceleration data. The processing will again be done using the AT&T 6300 computer. The averages and standard deviations of the acceleration frequency spectrums will be calculated and the treadmill test procedure will be compared to that of the wheelchair rolling over a stationary bump on a flat road surface. This qualification will use only four speeds with one bump height and one tire type. Forward acceleration variations will be studied with some thought given to developing a correction for the treadmill configuration data. In addition, the ISO dummy's acceleration response will be compared to a human's acceleration response from data taken on the treadmill system. The variation in mounting of the accelerometers and its effect on system response will be studied.

**Future Plans**—If time and resources permit, a study will begin on determination of trends for design of wheelchair systems to improve ride comfort based on these findings.

#### **Publications Resulting from This research**

None reported.

### **[162] Investigation of Sitting Pressures in Wheelchair-Bound Persons**

**F.R. Fisher, BSc, MD, FRCP(C); Micheal D. O'Riain, PhD, PEng; Louis Goudreau, BSc, PEng; Marlin Adams, RN**  
The Rehabilitation Centre, Ottawa, Ontario K1H 8M2 Canada

**Sponsor:** *The Royal Ottawa Health Care Group, The Royal Ottawa Hospital*

**Purpose**—The objective of this study was to make quantitative comparisons between sitting pressures in sling wheelchair seats and sitting pressures in wheelchairs having a cushion on a hard base. A measurement method was to be developed which could be used within the constraints imposed by a busy seating clinic (e.g., time constraints, difficulty in undressing subjects prior to measurements, difficulties in attaching pressure sensors directly on the skin surface, etc.).

**Methodology**—An Oxford Pressure Monitor was used for our measurements. We placed 33 cells on a thin flexible sheet, with locations designed so that appropriate pressure measurements were made of

the tuberosities, the coccyx, and the thighs. The sheet was placed on the wheelchair cushion or on the sling seat, and the subject sat on it as symmetrically as possible. Care was taken to ensure that the tuberosities, coccyx, and thighs were over the appropriate cell locations. The cells could then measure the pressures at these locations. Pressures on the sloping sides of the sling seat could also be measured. The use of 33 cells provided sufficient redundancy, so that the pressures at the different anatomical locations showed clearly as peak pressures.

**Results/Implications**—In all cases, the maximum pressures under the ischial tuberosities, the maxi-

mum pressures at the sides of the seat, and the maximum coccyx pressures were larger with the sling seat than with the cushion on a hard base. The magnitude of the increases in pressure due to the sling seat were large and of the same order of magnitude as capillary pressure.

Both seating systems exhibited pressures which were larger than capillary pressure. Thus, frequent relief of pressure is essential to prevent the formation of pressure sores, even when using a cushion seat. The sling wheelchair seats produce higher pressures than cushions on a hard base, and therefore, a higher risk of developing pressure sores.

Thus, all persons using wheelchairs for extended periods of time should avoid sling seats, as they result in an unnecessary increase in the risk of pressure sores.

**Future Plans**—Future work will measure back pressure as well as buttock pressure. Studies will also compare different types of cushions on a hard base.

#### **Publications Resulting from This Research**

**Sitting Pressures in Wheelchairs.** Fisher FR, O'Riain MD, Adams MA, Goudreau L, *Rehabil Res Can* 1(1):59-62, 1988.



# VI. Independent Living for the Disabled

*For additional information on topics related to this category see the following Progress Reports: [145], [496].*

## A. General

### [163] Design of a New Toilet: Transfer and Access

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**Sponsor:** *Rehabilitation Research and Development Unit Core Funds*

**Purpose**—The purpose of this study is to collect data on preferences of disabled people in their daily use of the bathroom. Such data include preference of approach, access, and transfer from a wheelchair to a toilet fixture by people capable of independent transfer, including: paraplegics, low quadriplegics, hemiplegics, amputees, etc. These data are necessary to prepare a proposal for the design of a new toilet.

**Progress**—The first task of this study required gathering data of user preferences in the bathroom. This was accomplished by preparing and analyzing an 8-page illustrated survey sent to 1800 randomly selected *Paraplegia News* subscribers. The survey was divided into three categories which addressed use of the toilet, the lavatory, and bathtub or shower. For each category, readers were asked to comment on their techniques for approach, transfer, and use of the fixture, in addition to type of assisting devices used, if their fixture was not satisfactory. Further, the survey requested information regarding the type of modifications readers had made in their homes.

**Results**—Eight hundred questionnaires were returned, thus yielding a 45 percent return rate. The breakdown of respondents includes: quadriplegics, 15 percent; paraplegics, 45 percent; multiple sclerosis, 25 percent; polio, 5 percent; hemiplegics, 2 percent; amputees, 1 percent; all others, 3 percent; not able to use the bathroom, 4 percent.

Following is a summary of responses for use of the toilet by participants capable of independent transfer: 1) side transfer: quadriplegics, 62 percent; paraplegics, 45 percent; multiple sclerosis, 32 percent; polio, 26 percent; hemiplegics, 7 percent; and, amputees, 12 percent; 2) frontal transfer: quadriplegics, 38 percent; paraplegics, 55 percent; multiple sclerosis, 68 percent; polio, 74 percent; hemiplegics, 93 percent; and, amputees, 88 percent.

These responses clearly indicate that the traditional transfer technique from the side is no longer the only method used by the disabled. This is an important finding that justifies evaluating a fixture that was not originally designed for access from a seated position.

**Future Plans**—The second task planned for this survey is to study access and transfer from a wheelchair to a toilet. This task seeks to study the manner by which disabled people transfer to the toilet, and the problems they experience. In particular, the study will focus on hand and body positions, reaching ability, transfer techniques, and the use of various types of grab bars. This transfer study protocol includes videotaping participants and submitting a questionnaire for participant response.

Data gathered in both tasks is expected to provide the necessary background material for preparation of a research proposal.

**Publications Resulting from This Research**  
None reported.



## [164] Effects of Electrical Stimulation on Chronic Spinal Spastic Bladder

James S. Walter, PhD; Charles J. Robinson, DSc; John S. Wheeler, MD; Robert D. Wurster, PhD; Talat Khan, PhD; Rebecca H. Sidarous, MS; Paul Zaszczurynski, BS

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Sponsor: VA Rehabilitation Research and Development Service (Project #B441-RA)

**Purpose**—This project's goal is to learn more about the mechanism of bladder dysfunction following spinal trauma and to use this knowledge to develop ways to manage urinary functions following injury. Minimally-invasive methods of stimulating sacral nerves and the pelvic floor are under investigation.

**Progress/Methodology**—Five spinal-injured cats (T1) have been instrumented with four epidural electrodes (Pisces Quad, Medtronic) implanted in the sacral canal adjacent to sacral nerves using a modified percutaneous procedure. Four of the animals were managed twice a day for 10 weeks with manual bladder expression (Crede procedure) or sacral stimulation using either the epidural electrodes or sacral surface electrodes. The fifth animal, part of a control group, is managed like the others, but not stimulated. All of the cats received daily nursing care and remained in excellent health throughout the experiment in accordance with the American Association for Accreditation of Laboratory Animal Care (AAALAC) guidelines.

In the early spinal cat, one-to-two-weeks post-injury, urodynamic responses to sacral stimulation, bladder filling, and Crede procedure (manual pressure) were noted. Bladder filling did not induce bladder contraction or voiding. Sacral stimulation with either implanted or surface sacral electrodes induced bladder contractions less than 40 mmHg without voiding, and Crede procedure induced minimal voiding which was interrupted by exaggerated urethral closure activity. This urethral reflex activity can best be described as a urethral emptying reflex (UER) where closure of the urethra during voiding both interrupted the urine flow and emptied part of the urethra of urine. This UER was indicated by pelvic floor and anal contractions. Occasionally, more peripheral responses, such as penile erection and leg flexion, were noted with the UER. Fluoroscopy confirmed the pelvic floor responses by show-

ing closure of the urethral sphincter interrupting voiding.

In the late spinal cat, three- to ten-weeks post-injury, the urodynamic pattern changed. The bladder could be easily emptied by Crede procedure. Bladder filling produced spontaneous bladder contractions with voiding. However, the UER still interrupted the voiding stream. Voiding responses to sacral stimulation were improved, but still left high residual urine. The UER, as described in the chronic spinal male cat, may be a mechanism contributing to the high urethral resistance (sphincter dyssynergia) seen in SCI patients.

Sacral nerve stimulation did not effectively empty the bladder in these chronic spinal animals; therefore, direct bladder stimulation was also investigated during terminal studies when the animals were under anesthesia. Although both stimulating procedures induced similar peak bladder pressures, direct bladder stimulation induced higher voiding rates. Direct bladder stimulation also induced voiding during and after stimulation; in contrast, sacral nerve stimulation only induced voiding after stimulation. These results indicate that direct bladder stimulation may be a better approach for neuroprosthetic control of the bladder than sacral nerve stimulation.

Repetitive, spontaneous, bladder contractions occurred when the bladder was full in the late spinal cats, and sacral and pelvic floor stimulation techniques were investigated to inhibit the contractions. Inhibition could not be demonstrated in two of the cats, probably because low current stimulation induced leg and bladder contractions. In the three other cats, the bladder was inhibited with stimulation of sacral nerves and/or the pelvic floor. In these animals, low frequency stimulation at low currents was most effective. It was determined that 3.5 pps was more effective than 10 or 35 pps. Long pulse durations of 350  $\mu$ s may have been better than short pulse durations of 35  $\mu$ s. Stimulating currents



that induced pelvic floor and anal contractions were generally effective for inhibiting the bladder. Also, pudendal nerve stimulation may be more specific for bladder inhibition than sacral nerve stimulation.

**Future Plans**—Work on the remaining experimental and control animals will be completed in the next six months. We plan to evaluate a multichannel implantable simulator for bladder control. Such systems have been or are being developed at Case Western University and Rancho Rehabilitation Engineering Center.

#### Publications Resulting from This Research

**Urodynamic Responses to Sacral Stimulation in the Chronic Spinal Dog.** Walter JS, Wheeler JS, Robinson CJ, Bolam MS, Wurster RD, *J Urol* 7:13-25, 1988.

**Role of the Urethral Emptying Reflex in High Urethral Resistance Following Spinal Cord Injury.** Walter JS, Wheeler JS, Sidarous R, Robinson CJ, Mueller D, in *Proceedings of the 35th Annual Meeting of the American Paraplegia Society*, 24, 1989.

**Effects of Filling Volume on Detrusor Contractility.** Walter JS, in *Proceedings of the 11th Annual Urodynamics Society*, 11-12, 1989.

**Urethral Reflexes in Spinal Cord Injured Cats.** Walter JS, Wheeler JS, Sidarous R, Wurster RD, *J Urol* 141:569A, 1989.

**Comparison of Sacral and Pudendal Nerve Stimulation for Bladder Inhibition in the Spinal Cat.** Walter JS, Sidarous RH, Wheeler JS, Robinson CJ, Zaszczurynski PJ, Wurster RD, *Neurosci Abst* (in press).

**Urethral Responses to Sacral Stimulation in the Chronic Spinal Dog.** Walter JS, Wheeler JS, Robinson CJ, Khan T, Wurster RD, *Amer J Physiol* (in press).

### [165] An External Urine Collection Device for Incontinent Women: Evaluation of Long-Term Use

**David E. Johnson, PhD; Jodie L. O'Reilly, RN, MAS**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B315-2DA)

**Purpose**—Chronic urinary incontinence is a common complication of spinal cord injury, multiple sclerosis, and other neurological diseases, and is a major clinical problem among aged women, particularly those in nursing homes. When other modalities of management fail, a urine collection device may be considered. Currently, more than 90 percent of women in nursing homes who require urine collection devices, use urethral catheters. While this method is effective in maintaining dryness, prolonged catheter use results in universal bacteriuria. An alternative option with less complications should prove beneficial to this population.

**Progress**—We report the use of an external urine collection device (Female Urinary Pouch, Hollister, Inc., Libertyville, IL) which is affixed to the perineum by an adhesive developed by the ostomy industry, and funnels urine into a bedside collector. Our preliminary evaluation of this device demonstrated it to be effective in a small number of women for up to 21 days. In the present study, we enrolled 26 women who ranged in age from 66 to 96 years old, and extended the duration of wear beyond

6 months, a time period more pertinent to the management of incontinence. Devices were replaced 48 hours after application, or more frequently if unacceptable leakage occurred. Assessment included determination of: 1) a clinically appropriate wear time; 2) adverse effects of use; and, 3) frequencies and other characteristics of any associated bacteriuria.

**Results**—We applied 2,461 external devices to these 26 women. Of these devices, 197 were electively removed, leaving 2,264 which could be evaluated. Almost 80 percent of the devices were in place and leak-free at 24 hours of wear, and almost half were still in place and leak-free at 48 hours. Mean wear time for all 2,264 devices was 36.2 hours  $\pm$  14.8 hours; median wear time was 43 hours, and the range was from 1 to 73 hours. We found no correlation between leak-free wear time and patient age, contractures, tube feedings, or care on a standard bed, water bed or air-flotation bed. We did, however, note a correlation between leak-free wear time and the transfer of a patient from bed to chair ( $p < 0.001$ ).



Erythema of the periurethral mucosa resulting from device usage was graded as 0, absent; 1+, slightly pinker than normal; 2+, red; 3+, beet red; 4+, break in skin. Periurethral erythema was observed after removal of 40/2461 (1.6 percent) devices. These erythemas were graded as follows: 1+, 26; 2+, 10; 3+, 4; there were no 4+ reactions. All erythemas resolved spontaneously with continued device use. In no patient was periurethral edema or vaginal discharge observed. No new decubitus ulcers formed in the 13 patients with existing decubitus ulcers, nor in the 13 patients who did not have decubitus ulcers at the onset of the study.

The incidence of bacteriuria with the urinary pouch was substantially lower (2.5 episodes per 100 days) than the incidence of bacteriuria in previously studied indwelling catheter patients (8.0 episodes per 100 days).

**Implications**—Previously-designed external devices for women have been associated with unacceptable wetness and adverse local reactions that have precluded continued use. In the present study, local perineal reactions were infrequently observed and, when present, were mild and transient. This device may offer an alternative method of care for the female incontinent patient. However, randomized trials will be required to determine whether long-term use of an external device will prevent the clinical complications associated with long-term use of the indwelling urethral catheter.

#### **Publications Resulting from This Research**

**Clinical Evaluation of an External Urine Collection Device for Nonambulatory Incontinent Women.** Johnson DE, O'Reilly JL, Warren JW, *J Urol* 141:535-537, 1989.

## **[166] Capuchin Monkeys as Aides for Quadriplegics**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B152-RA)

**Purpose**—The purpose of this study was to train capuchin monkeys to serve as aides to mid- and high-level quadriplegics.

**Results**—In May of 1989, the VA Rehabilitation Research and Development Evaluation Unit released the results of their evaluation of the efficacy of capuchin monkeys to serve as aides for quadriplegics. After visiting the homes of nine quadriplegic users, the evaluator reported that monkey helpers readily performed a variety of tasks for their disabled owners. Not all monkeys performed the same repertoire of behaviors, as each animal's task behaviors were designed to meet the needs of its particular owner. The evaluator, however, observed that in all, the monkeys performed 60 different assistive behaviors. The highest number of assistive tasks was performed by a monkey named Hellion, who completed 28 different tasks for her owner, with whom she had lived for 10 years. The lowest number of tasks was performed by Jeep, a monkey who performed 6 different tasks, but who had been with his owner for only 5 months.

The evaluator reported that the monkey helper's presence in the home had increased the quadriplegic's independence of human assistance. For example, users reported that the average number of hours per day spent without a human caretaker prior to obtaining a monkey helper as 0.4 hours. With the assistance of a monkey helper, quadriplegics reported spending on average of 5.9 hours per day without human assistance.

Lengthy interviews with the users revealed that aggressive or undesirable monkey behavior occurred minimally or not at all. None found their monkey's daily behavior a problem. Interviews with family members and/or attendants revealed that the feeding, cleaning of the cage, and grooming of the monkey was acceptable to them. Discussions with quadriplegics concerning illnesses experienced by their monkeys during the years in which they had cohabitated, revealed that these animals are physically hearty and require infrequent veterinary care.

The results of the VA evaluation were released to members of Congress who are considering the passage of legislation that would authorize the



Department of Veterans Affairs to purchase monkey helpers for certain service-connected quadriplegic veterans. Helping Hands, a non-profit organization established to implement the research results, is focusing its efforts on the refinement of methods by which monkey helpers can be trained on a larger scale. Should enabling legislation be passed, service-

connected quadriplegic veterans will receive the highest priority for the limited number of monkey helpers available.

#### **Publications Resulting from This Research**

None reported.

### **[167] Instrumental Social Support as a Buffer of Psychological Stress for Persons with Physical Disabilities**

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**Marcus J. Fuhrer, PhD; Margaret A. Nosek, PhD; Carol Potter, MS**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—This study is designed to test the hypothesis that instrumental social support, specifically assistance with activities of daily living, is a key factor in determining the degree to which physically disabled people experience stress and psychological dysphoria.

Upon receipt of completed surveys, the researchers interviewed subjects by telephone concerning their levels of social support. Approximately 81 percent of subjects returned surveys and participated in telephone interviews. Currently, analyses of the data are underway.

**Progress**—Staff in eight Centers for Independent Living in Federal Region VI recruited subjects for the study and distributed questionnaire packets.

#### **Publications Resulting from This Research**

None reported.

### **[168] Operational Definition of Independence**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—This project is designed to develop an operational definition of independence that incorporates three dimensions of the term: perceptions of control over one's life, psychological factors, and behavioral or functional characteristics. The objective is to develop an assessment instrument to quantify an individual's independence in each of the above specified domains.

from Flanagan's quality of life domains (1978); items from Fordyce's Independence Scale (1954), which deals with psychological factors such as competitiveness, self-esteem, and group autonomy; and sections from The Arthritis Impact Measurement Scale (AIMS) (Meenan, Gertman, and Mason, 1980), a Guttman-type ordering of general functional ability items.

**Progress**—After extensive search of the literature and expert consultation, the Personal Independence Profile (PIP) was constructed to operationalize the consensus definition. The PIP consists of items measuring perceived control over one's life, selected

Initial testing of the PIP with 61 people with severe physical disabilities resulted in Cronbach's alpha coefficients ranging from 0.71 to 0.89 for the control and psychological independence sections. Reliability estimates of the five parts of the AIMS yielded coefficients of reproducibility from 0.87 to

0.93. A manuscript is in preparation describing relationships between PIP scores and personal, demographic, and behavioral characteristics of the 61 subjects.

The next step in the development of the PIP was to conduct various tests of its validity. Two hundred subjects in 10 Centers for Independent Living (CIL) across the country were sent the PIP, 120 of whom also completed questionnaires de-

signed to measure the same or similar constructs to test the convergent validity of the PIP. In addition, CIL staff who knew the subjects well, rated each person on a global rating scale. Currently, data are being analyzed.

#### **Publications Resulting from This Research**

None reported.

### **[169] The Definition of "Peer": Consumer Perspectives and Significance in the Delivery of Counseling Service**

**Margaret A. Nosek, PhD; Marcus J. Fuhrer, PhD; Laurie Gerken; Laurel Richards**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—This project was intended to provide initial data on the perceptions of disabled persons with respect to the definition of peer and the provision of counseling services by peers. Peer counseling is an essential aspect of consumer involvement in independent living programs as evidenced by the fact that all independent living programs receiving funding under Title VII of the 1978 Amendments must include peer counseling as a core service.

**Progress**—The quasi-experimental design of this project focused on perceptions of counselor credibility. The research question asked which factors account for the greater variance in ratings of counselor credibility: disability status of the counselor, whether or not the counselor was professionally trained, and whether or not the content of the interaction was disability-related. Seventy-two subjects completed a modified version of the Counselor Effectiveness Rating Scale (Barak & LaCrosse, 1975) after viewing photos of four counselors, reading and hearing biosketches for each, and listening to tape recordings of two consumers describing a problem to a counselor.

**Results**—The data were analyzed using a doubly multivariate repeated measures analysis of variance within subjects factors (professionalism, disability, and vignette content, each with two levels) and five dependent variables (experience, expertness, interest, understanding, and ability). Although the three-way interaction among professionalism, disability and vignette content was not significant, all three multivariate two-way interactions were statistically significant. An important finding of the study is that disability status of counselors significantly affected the ratings. For both professionals and nonprofessionals, disabled counselors received higher mean ratings than did nondisabled counselors on all five measures, although this difference was smaller for professionals. Also, for the disability content interaction, subjects rated disabled counselors more favorably than nondisabled counselors on all five measures. Preparation of articles to disseminate these results is in progress.

#### **Publications Resulting from This Research**

None reported.



## **[170] Interface Devices for Helping the Handicapped to Communicate with Contemporary Servo-Electronic Devices**

**Roy S. Brown**

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**Sponsor:** *National Institute of Child Health and Human Development, National Institutes of Health*

**Purpose**—This project is directed at developing an interface device, based on digital signal processing (DSP) technology, which can filter intended and unintended motions created by physically handicapped individuals to produce a more coordinated output. The basic supposition is that the filtered output will enable such individuals to access such “contemporary servo-electronic devices” as robots, computers, wheelchair controls, and so forth, at a higher success ratio, and consequently, at a signifi-

cantly reduced frustration quotient. In addition to the direct benefits that will arise from improved access, it is asserted that improved self-reliance will enhance self-esteem, and therefore propel the learner still further toward meaningful independence.

### **Publications Resulting from This Research**

None reported.

## **[171] An Exercise Machine for Wheelchair Users**

**Theodore E. Lambert**

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**Sponsor:** *National Institute of Child Health and Human Development, National Institutes of Health*

**Purpose**—Approximately nine million people in the U.S. are using wheelchairs due to chronic disabilities. These people would derive tremendous benefit from access to an exercise machine.

The goal of this project is to develop a high quality, low cost, safe, easy to use wheelchair-based exercise machine. The machine will be especially useful for individuals who are not able to get out of a wheelchair on their own.

The machine provides continuous passive mo-

tion of the legs, arms, and torso, at variable rates. It also allows voluntary muscle contractions to be performed simultaneously with passive exercise. Phase I research and development will focus on improving the design and construction of an existing prototype device to enhance performance, to refine safety features, and to reduce manufacturing costs.

### **Publications Resulting from This Research**

None reported.

## **[172] Biofeedback Devices Using Home Computers**

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**Sponsor:** *The Royal Ottawa Health Care Group, The Royal Ottawa Hospital*

**Purpose**—The objective of this project is to make home biofeedback systems available to owners of home computers. Physiological parameters for feedback will include: limb movement, electromyogram

(EMG), and others as needed. Our specific goals are: 1) to motivate a patient to exercise and to continue his or her therapy at home; 2) to monitor the performance of a patient, by storing his perfor-

mance on diskettes; and, 3) to give visual and/or auditory feedback as an immediate reward for doing a good job.

**Methodology**—An interface board will be developed to accept such inputs as force transducer, EMG, and limb position. The board will be connected to the joystick of the mouse input of a home computer owned by the patient. Special hardware and software will have to be developed to monitor certain physiological parameters, to transmit them to the home computer, to process them, and to display them appropriately.

### [173] Development of an Infant Crib to be Used by Physically Disabled Parents

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**Sponsor:** *The Royal Ottawa Health Care Group, The Royal Ottawa Hospital*

**Purpose**—The objective of this project is to develop a crib that is easily accessible by a wheelchair-bound or otherwise physically disabled parent. Our specific goals are: 1) to make a crib that is easily accessible to a parent in a wheelchair; 2) redesign the main opening on the crib so that it is easy for wheelchair-bound persons to put the infant into the crib, and take the infant out; and, 3) ensure that all government regulations for cribs are fully met, and that the crib is perfectly safe for both infant and user.

**Methodology**—For our initial prototypes, it was decided to modify existing infant cribs rather than build a complete unit. The following changes were made to a conventional crib: 1) each leg was lengthened by 15 inches. This meant that the crib was high enough (26 inches above the ground) so that the knees of a wheelchair-bound person could fit underneath; 2) sliding doors were placed on one side of the crib, making it easy for a person in a

**Progress**—A child with cerebral palsy is using this technique to train the rotation of her femur prior to corrective surgery. Following the surgery, the bio-feedback system will be used to monitor progress.

**Future Plans**—New applications will be found for this system, and it will be expanded to work on more and different types of home computers.

#### **Publications Resulting from This Research**

None reported.

wheelchair to put an infant in or take an infant out; and, 3) a second set of inner "half-height" doors were provided to prevent the infant from rolling out while the main doors were being opened.

**Progress**—Two of the three prototypes are now being used by wheelchair-bound mothers and their infants. Feedback from the two users has been very positive, and has enabled us to make improvements to the design. There also is interest in the crib among non-wheelchair-bound persons, because of easy access to the infant. Negotiations are under way to have the crib manufactured commercially.

#### **Publications Resulting from This Research**

**A Crib for Use by Wheelchair-Bound Parents.** O'Riain MD, Layeux G, in *Proceedings of the S.M. Dinsdale International Conference in Rehabilitation*, 50-51, 1988.

**The Design of a Crib for Use by Physically Disabled Parents.** O'Riain MD, Layeux G, in *Proceedings, ICAART 88*, Montreal, 242-243, 1988.



## [174] Development of Systems to Enable Physically Disabled Persons to Board Inter-City Buses

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Sponsor: Transport Canada

**Purpose**—Our purpose was to develop two systems which will enable physically disabled persons to board standard inter-city buses. Both systems will be station-based (i.e., permanently stored in the departure and arrival bus stations). The first system is to be based on a folding ramp, and the second system is to be based on a stair-lift mechanism (similar to that used by physically disabled persons in their homes).

Our specific goals are: 1) to construct full-size operational mock-ups of the two systems; and, 2) to test the two operational mock-ups and report on the results.

**Methodology**—After making a thorough investigation of existing bus-boarding systems, we concluded that both of our designs should start with a transfer from the client's own wheelchair, to a special wheelchair which was small enough to fit through the entrance of a standard inter-city bus, and then be brought beside the first row of seats. The transfer from the client's wheelchair to the special chair could be done at any convenient location (e.g., inside the bus terminal). With the special chair brought beside the first row of seats, a level transfer could be made to a bus seat if the armrests on each side of the aisle of the front row could be pivoted upwards. This pivoting upwards of the armrests is necessary for the level transfer and also to give the necessary aisle-width required by the special chair.

The changes to the armrests are the only bus modifications required by either of our systems. We

have succeeded in avoiding making any of the other changes considered, including: modifying the bus door to open to a full 90 degrees; making the modesty panel at the entrance to the bus removable; or, making permanent attachments to the bus itself. Thus, our designs avoid expensive modifications to buses, an important advantage.

**Progress**—Two full-size mock-ups have been constructed, and preliminary tests have been performed. More in-depth tests will be done.

**Results/Conclusions**—Both methods appear to work very well. However, an inescapable limitation will always remain due to the small size of the entrances to standard inter-city buses. The new systems are designed so that they will not add to the existing space constraints. In this respect, they achieve their goal.

**Future Plans**—Future work will involve constructing operational prototypes that can be installed in various bus terminals throughout Canada. This will enable all aspects of the operation of these systems to be studied, including required operator training, performance of the systems over time, time delays to regular bus schedules caused by these systems, client acceptance, etc.

### Publications Resulting from This Research

**Novel Station-Based Boarding Device Concept for Inter-City Bus Applications.** O'Riain MD, *Final Report for Contract #T8080-6-2663/01/FT*, Supply and Services, Canada, 1987.

## [175] Physiological Capacities for Work of Persons with Neurophysical Impairment

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Wichita State University, Wichita, KS 67208

Sponsor: *Wichita State University; Rehabilitation Engineering Center, Wichita, KS*

**Purpose**—The basic objective is to document occupational tasks and daily living tasks performed by individuals with cerebral palsy. These tasks carried out at the workplace and home will be simulated in a laboratory setting to enable physiological responses to be measured. All subjects will be ambulatory adults with cerebral palsy.

**Methodology**—Tasks performed by employees with disabilities at the Center Industries Corporation (Wichita, KS) were recorded with a video camera. Additionally, daily living tasks performed by two individuals with cerebral palsy (one ambulatory, one non-ambulatory) were recorded.

A time and motion study was performed on the taped footage. The following information was obtained to be used to simulate tasks in a lab setting: 1) flow diagrams; 2) activity charts; 3) man-machine

charts; 4) operation charts; and, 5) breakdown of tasks into elements.

Physical work capacity will be measured on both ambulatory and non-ambulatory adults with cerebral palsy and able-bodied adults doing a submaximal test on a Schwinn AirDyne Ergometer.

**Progress**—Data collection began on August 28, 1989 and was completed in November of 1989. A total of 15 subjects were tested. These subjects began an aerobic conditioning program in October, 1989. At the end of the aerobic conditioning program all physiological capacities will be re-tested on the simulated tasks to see if any improvement occurred as a result of the aerobic conditioning.

**Publications Resulting from This Research**  
None reported.

## B. Robotics

### [176] Clinical Evaluation of a Vocational Desktop Robotic Aid for Severely Physically Disabled Individuals

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David Lees, MS; Dean Chang, BS  
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Sponsor: *VA Rehabilitation Research and Development Service (Project #B239-2RA)*

**Purpose**—Computer technology can provide a modicum of independence for disabled individuals and is becoming a fast-growing field of employment for the disabled; however, computers alone fail to address the manipulation needs of individuals who have no use of their arms and legs. In order to address this need for independence in the worksite and to provide a vocational tool for the severely physically disabled, a vocational desktop robotic assistant (DeVAR-IV) has been developed and is

currently undergoing evaluations at the worksites of disabled individuals employed in the computer field.

**Progress**—The robotic aid being evaluated is a Westinghouse PUMA-260 industrial arm controlled by an IBM-PC/AT computer and operated by user commands through a VOTAN voice unit. Prior workstations involved the use of DeVAR in performing activities of daily living (ADLs), such as preparing a meal, feeding, brushing teeth, washing



the face, and shaving. This ADL system was evaluated by 25 high-level quadriplegics with positive results in terms of robot task performance, reliability, voice recognition accuracy, and safety. Based on feedback from users, a fourth-generation vocational workstation was developed to address the need for productive employment of quadriplegics in the computer industry.

The vocational system was built in an L-shape using Herman Miller modular furniture. The robotic arm was mounted upside-down over the workplace on a 4-inch custom-designed track. A linear encoder sensor was added in the Otto-Bock Greifer to measure hand opening and detect the presence of objects. A monitor showing robot command prompts is placed within the user's line of vision. A separate computer runs the user's own application software. An adjustable stand attached to the front of the table holds the keyboard, meal tray, mouthstick, and individual papers.

This vocational system was initially placed at Disabled Programmers, Inc., with a C3-level, respiratory-dependent quadriplegic student. A base set of vocational and daily living tasks was developed. The system was next placed in the office of a C4-level quadriplegic who works as a systems programmer at a major utility company in San Francisco. For the past 2 months, this individual has been using the system to perform the following tasks: 1) prepare lunch (refrigerator); 2) feed with utensils (fork, spoon); 3) get a drink of water; 4) dispense medications and throat lozenges; 5) retrieve mouthstick for typing; 6) retrieve papers and arrange them for viewing; 7) tear off sheets from printer and place within sight; 8) answer phone and bring receiver to ear for private conversation; 9) page through fanfold printouts; and, 10) operate EUC (lamp, computer, printer, robot).

**Results**—DeVAR-IV has been in use with a disabled programmer for 2 months. In order to evaluate its effectiveness, data are being collected from computerized history lists, direct observation by the occupational therapist, and video recordings. The system has been providing approximately 4-6 total hours of independence daily in the desktop environment. The robot has been consistently performing the base set of tasks; however, new advanced tasks have been identified and are being addressed in order to provide independence to the user for an extended period of time. This includes allowing the user to switch between the application and robot computers in order to retrain voice sets and to dial out on the phone.

**Future Plans**—Based on the success of this evaluation, future plans include placing and evaluating the system at other disabled individuals' worksites.

#### Publications Resulting from This Research

**Design of a Second Generation Desk-Top Robotic Aid.** Lees D, Crigler R, Van der Loos HFM, Leifer LJ, in *Proceedings of the 10th Annual RESNA Conference*, San Jose, CA, 796-798, 1987.

**Evaluation of a Table Top Robotic Aid for Quadriplegics.** Hall KH, Glass K, Hammel J, Leifer LJ, Perkash I, in *Proceedings of the 10th Annual RESNA Conference*, San Jose, CA, 776-777, 1987.

**Clinical Evaluation of a Desktop Robotic Aid for Severely Physically Disabled Individuals.** Hammel JM, Hall KH, Van der Loos HFM, Leifer LJ, Perkash I, in *Proceedings, ICAART '88*, Montreal, 448-449, 1988.

**A Third Generation Desk-Top Robotic Assistant for the Severely Physically Disabled.** Lees D, Crigler R, Van der Loos HFM, Leifer LJ, in *Proceedings, ICAART '88*, 450-451, Montreal, 1988.

**Clinical Evaluation of a Desktop Robotic Assistant.** Hammel JM, Hall KH, Lees D, Leifer LJ, Van der Loos HFM, Perkash I, Crigler R, *J Rehabil Res Dev* 26(3):1-16, 1989.

**Design and Evaluation of a Vocational Desktop Robot.** Van der Loos HFM, Hammel JM, Schwandt D, Lees D, Leifer LJ, Perkash I, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 107-108, 1989.

### [177] High Speed Obstacle Avoidance (Mobile Autonomous Robot Base for Rehabilitation Applications): A Pilot Study

Simon P. Levine, PhD

VA Medical Center, Ann Arbor, MI 48105

Sponsor: VA Rehabilitation Research and Development Service (Project #B989-PA)

**Purpose**—The purpose of this pilot study is to implement a high speed obstacle avoidance system

on the Denning Robot. This system will allow the robot to travel at normal walking speeds and

automatically steer around obstacles in its path with little or no slowing.

**Methodology**—The obstacle avoidance system will include an upgrade of the Denning on-board host computer from a 68000 to an 80386 based system. This is required for increased processing speed and an improved development environment. We will then develop interface software between the 80386 host computer and the ring of 24 ultrasonic sensors which come as standard equipment on the Denning. The final step will be the porting of the previously developed obstacle avoidance algorithms to the Denning robot.

Testing of the obstacle avoidance system will occur within the laboratory setting using a variety of simple and complex obstacle configurations. Testing will be staged by degree until the robot is capable of maneuvering around wall partitions, furniture pieces, moving obstacles (people, other robots), etc. Similar tests have been successfully performed by the Robot Systems Division.

**Publications Resulting from This Research**

None reported.

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**[178] Global Travel (Mobile Autonomous Robot Base for Rehabilitation Applications): A Pilot Study**

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**Simon P. Levine, PhD**

VA Medical Center, Ann Arbor, MI 48105

**Sponsor:** VA Rehabilitation Research and Development Service (Project #B990-PA)

**Purpose**—This pilot study entails the implementation of both a global path planning and an absolute positioning system. These systems are intended to allow a Denning DRV-1W mobile robot to store information about the environment in a *world model* and then compute or plan optimal paths in order to navigate within known environments. Proposed work for the global travel system includes the modification of the artificial intelligence tree search algorithm, A\*, for the determination of an optimal path. The other part of the global travel system, absolute positioning, is needed in order for the robot to be able to determine its location within the known environment. It is planned to utilize an infrared beacon positioning system (already obtained from Denning). This system utilizes uniquely identifiable infrared sources mounted in the environment from which the robot can calculate its absolute position through triangulation.

**Methodology**—The global travel system will be tested by setting up a laboratory simulation of a multi-room environment with “corridors” and “offices.” Testing and development will proceed until the robot is capable of determining its current location within the known environment and calculating an optimal path to a preassigned target. For the purpose of the global travel pilot project testing, no unknown obstacles will be present.

**Future Plans**—Future work will include the integration of global travel and obstacle avoidance, allowing the robot to maneuver around unknown obstacles while traveling anywhere within the known environment.

**Publications Resulting from This Research**

None reported.



## [179] Companion Tracking (Mobile Autonomous Robot Base for Rehabilitation Applications): A Pilot Study

**Simon P. Levine, PhD**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #B991-PA)*

**Purpose**—The purpose of this pilot study is to design, develop, and implement a nonphysical link between a robot (Denning DRV-1W mobile robot) and a user *companion*. The goal of the companion tracking system is to allow the robot to autonomously follow the user (or even lead in some cases) and minimize the level of interaction required to accompany the user. Three alternate designs are proposed for study. All are based on readily available technologies. An optimal system will be defined on the basis of an evaluation of these systems and a full working prototype system developed for testing.

The companion tracking system will be tested in small steps to ensure the safety of a companion. The final goal for this pilot project will be to have the robot able to track a companion within the laboratory setting, staying within a range of 0.5 to 2.0 meters, even with other individuals crossing between the robot and companion.

### **Publications Resulting from This Research**

None reported.

## [180] A Mobile Robotic Aid for Severely Handicapped People

**Michael Regalbuto; John Cheatham; Thomas A. Krouskop, PE, PhD**

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The Institute for Rehabilitation and Research, Houston, TX 77030

**Sponsor:** *The Clayton Foundation for Research*

**Purpose**—The purpose of this project is to provide a cost-effective aid to handicapped people in performing tasks of everyday living, supplementing paid human assistants.

**Methodology**—A machine control interface has been developed, which transduces head motion into a variety of control signals, including those needed to control a wheelchair, the cursor of a personal computer, and a musical synthesizer. Software on a MacIntosh SE supports an interface between the user and his environment, allowing him to command a modified HERO 2000 robot as well as to turn household appliances on and off. The user creates a model of his environment, complete with robot and appliances, using cursor-controlled interactive graphics similar to MacDraw and MacDraft applications. Once the model is complete, the user generates on-off commands for the appliances and task-level commands (e.g., move between rooms, pick up

an object) for the robot by manipulating the model. The robot can also be moved joint-by-joint using a graphic control panel.

**Progress**—The machine control interface and software for controlling the robot joint-by-joint has been operational for over 2 years. Software development for modeling the environment and generating task-level commands is nearing completion.

**Results**—The machine control interface has been demonstrated in controlling a wheelchair and in running software on Apple and Macintosh computers since 1987. The robot and graphic control panel software were placed in a user's home in the Spring of 1988, with an encouraging response. Software for modeling the robot and its environment was used to command the robot in a demonstration at NASA (Johnson Space Center) in July of 1989.



**Implications**—The system under development will have a great impact on the cost and availability of assistance to the handicapped in meeting their needs of mobility, employment, entertainment, and overall personal independence. The system can be used by nonhandicapped people as well, and can serve as an inexpensive testbed for research in autonomous mobile robotics and tele-operation.

#### **Publications Resulting from This Research**

**A Mobile Robotic System as an Aid for the Severely Handicapped.** Cheatham JB, Regalbuto MA, Krouskop TA,

Winningham DJ, in *Proceedings of the 9th Annual International Conference of the IEEE/EMBS*, 9:1100-1101, 1987.

**A Robotic System for Improved Living by Severely Disabled Persons.** Regalbuto MA, Cheatham JB, Krouskop TK, in *Proceedings of the 1988 IEEE International Workshop on Intelligent Robots and Systems*, 79-82, 1988.

**A Navigation System Framework for a Mobile Robot.** Regalbuto MA, Fisher PB, Adnan S, Norwood JD, Weiland PL, in *Proceedings of the 10th Annual International Conference of the IEEE/EMBS*, 10:1511-1512, 1988.

**An Object-Oriented Graphics Interface for Controlling a Mobile Robot.** Regalbuto MA, Cheatham JB, Krouskop TA, in *Proceedings of the 11th Annual International Conference of the IEEE/EMBS* (in press).

### **[181] Clinical Evaluation and Human Performance Studies on Prescribing Robotic Manipulators for Severely Disabled Individuals**

**David M. Horowitz, SM; Harry Webster, MD, MPH; Jeffrey M. Hausdorff, SM; Harriett Gordon, OT; Eric Quintin, BSEE**

Rehabilitation Engineering Program, Department of Rehabilitation Medicine, Tufts University School of Medicine, New England Medical Center, Boston, MA 02111

**Sponsor:** *Office of Special Education Programs, Department of Education*

**Purpose**—As part of an overall program to provide supported employment services to severely physically disabled individuals with a robotic workstation, we recognized a need to develop more reliable protocols for client evaluation and better quantitative techniques for the assessment of human productivity with the aid of a robotic manipulator. The purpose of this study is to develop a clinical evaluation protocol and to determine the effectiveness of a robotic manipulator intended to improve the productivity levels of individuals with severe motor impairments.

**Methodology**—Using a multidisciplinary team approach, individuals referred to the Rehabilitative Robotics Program are evaluated with respect to medical, physical, psychological, and vocational status. Individuals enroll in a preliminary training process in which they obtain limited experience in using the Tufts-New England Medical Center Robotic Workstation. During the training process, individuals learn to command the robotic manipulator by voice to acquire a variety of objects typically found in an office setting. Concurrently, individuals are tested on a set of controlled trials to enable us to determine the system's utility in partially restoring lost arm function. Individuals perform repeated

trials of object acquisition and object placement on a set of tasks of varying difficulty according to Fitt's Index of Difficulty. Task completion time is analyzed with respect to voice recognition accuracy, command vocabulary content, inter-command interval and motion repeatability. The individual's performance is studied with respect to accrued experience with the robotic system and accrued experience on the controlled task.

**Future Plans**—Results from the multidisciplinary team evaluation and quantitative performance study will be used to determine the appropriateness of prescribing a robotic manipulator for a given individual. Over the next year, it is anticipated that approximately ten individuals with quadriplegia due to varying causes will be evaluated. Results from this study should provide some of the necessary data to assess the appropriateness and effectiveness of employing a commercially available robotic manipulator to partially restore lost arm function.

#### **Publications Resulting from This Research**

None reported.



## [182] Pre-Vocational and Educational Applications of Robotics

**David M. Horowitz, SM; Jeffrey M. Hausdorff, SM; Joyce Knezevich, BSME**

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**Sponsor:** *Office of Special Education Programs, Department of Education*

**Purpose**—Small low-cost robotic arms (Esched Scorbot ER-III) have been placed in two long-term educational/clinical environments for evaluation. The premise is that the physical limitations of a person can be partially overcome with a mechanical arm that is under the person's control. The mechanical arm is flexible and can be accommodated to a number of different tasks, opening new opportunities of exploration, independence, and learning to severely disabled students.

**Progress**—The two selected educational/clinical sites include the Campus School at Boston College in Chestnut Hill and the Massachusetts Hospital School in Canton. The students range in age from 5 to 23 years. Both schools provide comprehensive educational and vocational services.

A portable and flexible software development environment called CALVIN has been developed and designed specifically for rehabilitation applications. CALVIN was used to develop a set of applications for use at the two educational/clinical sites. The applications include *Helpmate*, a package that allows students to acquire and sort objects; *Switchboard*, an application that allows vocal students to operate the AT&T switchboard; *Painting*, which allows students to use paint pictures with

three different colors; and *Tic-Tac-Toe*, an application that allows the students to participate in games and interact with one another, an experience that is rare for some of the students.

**Future Plans**—Results from the application of low-cost robotic manipulators in the two educational/clinical settings have been promising. Some of the students have grown fond of the opportunity to work with the robots and demonstrate considerable enthusiasm when given the opportunity to do so. CALVIN has not demonstrated to be usable by nonengineers. Therefore, the applications the students operate do not enable them to modify the arm's actions in a time-efficient manner to suit their needs. To give students more programmable control over the arm, future plans include developing an iconic graphical interface that allows them to plan their own robotic trajectories with a user-interface that is intuitive and easy to use. Educational software found in the Apple Macintosh environment will be reviewed as a basis from which to design the new robotic control software.

### **Publications Resulting from This Research**

None reported.

## [183] A User-Intuitive Vocational Robotic Workstation

**David M. Horowitz, SM; Jeffrey M. Hausdorff, SM; Steven S. Carroll, SB**

Rehabilitation Engineering Program, Tufts University School of Medicine, New England Medical Center, Boston, MA 02111

**Sponsor:** *Office of Special Education Programs, Department of Education*

**Purpose**—This work was completed in order to provide individuals with quadriplegia an appropriate set of tools to enhance their vocational competitiveness. A voice controlled vocational robotic workstation was designed to suit the vocational needs of individuals who lack motor ability. The utility of a

voice controlled robotic workstation is dependent on a system which functions under the command of the user so that it is amenable to the user's changing needs. A user-intuitive human-machine interface which functions as a voice commanded robot programming language was designed with the intent to



enable technically nontrained individuals to customize and command a robotic manipulator. Parallel work on a sensory feedback mechanism that automates grasp has been completed to enhance the user's productivity by minimizing the time it takes to teach the robotic manipulator new motions.

**Methodology**—Several constraints served as the design criteria for the system: 1) users should not be required to learn a complex robot programming language; 2) users should be able to execute predefined tasks; 3) users should be able to easily teach the robotic manipulator new tasks without relying upon engineering support; 4) the cost of the system must be reasonably contained and the amount of engineering resources invested in developing the system must be limited; 5) the system should manage the user's dialogue without the need of a natural language processing system; and, 6) the sensory feedback system should be seamlessly integrated into the user interface and allow the user to interact with it.

**Progress**—The workstation incorporates a Universal Machine Intelligence RTX robotic manipulator and a Kurzweil Voice System 1000 word recognizer. In addition, the system can incorporate a Kurzweil Voice Writer 10,000 word recognizer to transcribe office correspondence. An expert system was implemented to manage the user's dialogue with the programmable robotic manipulator and speech recognizer. A knowledge base is maintained that contains a model of the robot's world by associating sequences of motions with phrases the speech recognizer accepts. The system functions as a Robot Motion Editor, allowing the user to edit the knowledge base. The sensory feedback system includes a narrow beam ultrasonic sensor, and 2 thru-beam

and 2 retroreflective photoelectric sensors. A novel algorithm is employed to detect an object, to recognize its shape and orientation, and to plan a stable grasp.

The user interface represents the state of the system in a menu environment that organizes the user's vocabulary according to objects in the robot's world. User-taught phrases are associated with these objects and invoke robotic manipulation on the objects. Because the menu environment serves as the interface to an expert system, the Robot Motion Editor can be defined as a robot programming language as well as a user interface. As in any robot programming language, sequences of motions can be taught and system state can be checked. Because an expert system approach is employed, the Robot Motion Editor maintains the overhead associated with implementing functions for the user, minimizing the user's cognitive load. Initial testing of the system in the laboratory has shown that individuals can learn to use this system.

**Future Plans**—Future tests will be performed to evaluate the system's utility in an office or other vocational setting.

#### **Publications Resulting from This Research**

**Design of a Human-Machine Interface of a Voice Controlled Vocational Robotic Work Station.** Horowitz DM, Hausdorff JM, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 117-118, 1989.

**Sensory Feedback and Automated Grasping for a Vocational Work Station.** Hausdorff JM, Horowitz DM, Carroll SS, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 183-184, 1989.

**A User-Intuitive Speech Control Language for Text Processing and Robotic Task Planning.** Horowitz DM, Hausdorff JM, *J Am Voice I/O Soc* 6:28-46, 1989.

**The Structure and Function of a Speech Control Language for Text Processing and Robotic Control.** Horowitz DM, Hausdorff JM, in *Proceedings of the 11th Annual International IEEE/EMBS Conference* (in press).



## [184] Target-Centered Hybrid Force/Position Control of a Robot Manipulator

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*Sponsor: Nemours Foundation*

**Purpose**—The project objective is development of a robot manipulator to allow a disabled person to perform tasks such as shaving, hair grooming, and face washing. Because the robot hand must be in contact with the head during these tasks, the user must be able to control the force exerted by the robot as well as its position.

**Methodology**—The target-centered control aspect of the project will allow the user to control the motion of the robot hand about the head as a target. The user will have continuous control of the azimuth and elevation angles of the robot hand as it “wipes” the surface of the head. The hybrid force/position control aspect of the project will allow the user to simultaneously control the force exerted toward the target over the surface of the head.

**Progress**—Target-centered control in a plane has been demonstrated. Rapid progress has been made possible through the use of the Robot Programming Library developed by the Robot Programming Environment Project at the Applied Science and Engineering Laboratories of the A.I. DuPont Institute.

**Results**—An RTX robot (trademark, Universal Machine Intelligence) under PC control with the resident Robot Programming Library, was programmed to allow a user to control the robot hand to follow an arc about a target. This was accomplished by considering the robot links to be members of a theoretical 4-bar linkage. The user specifies the velocity of the “sweep” angle. The computer then continuously computes the speed of the shoulder, elbow, and yaw axes that cause the hand to follow this path.

**Future Plans/Implications**—The next step in the project will be to augment 2-dimensional case to implement 3-dimensional target-centered control. The development of hybrid force/position control will require some hardware modification, which will be introduced at the appropriate time.

### **Publications Resulting from This Research**

None reported.

## [185] Analog Control Project

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*Sponsor: Nemours Foundation*

**Purpose**—The purpose of the project is to develop and implement an effective strategy for the control of a human-scale manipulator by persons with physical disabilities severe enough to critically impede their ability to physically interact with the environment.

Specifically, the project proposes to research the implementation of a real-time, direct control

(also known as telemanipulation), analog control or master/slave control system. Since the system is intended for use by persons with disabilities, this project further seeks to address the human factors issues by researching and developing methodologies and tools for optimizing the user interface. These objectives combine to create a research effort that will address the need in rehabilitation robotics for

an interactive, flexible control system which makes the robot a natural extension of the person controlling it, thereby making the system more versatile and efficient.

**Methodology**—This project will require an input device capable of transmitting analog signals to the system. The device selected is the DataGlove from VPL Research. The DataGlove is a latex glove fitted with flex sensors and a Polhemus 3Space sensor. The glove is capable of transmitting analog signals via an RS232 serial connection to a microprocessor. These signals provide information concerning the location, orientation, and configuration of the hand. Low-level primitives for the DataGlove will be developed which allow the interpretation and processing of the analog signals so they can directly interface with a robot system.

The Analog Control Project will also require a robot with fully accessible drivers. As part of

developing a standardized robot interface, low-level primitives for the control of the RTX robot are also being developed.

**Progress**—Work accomplished to date has focused primarily on the development of appropriate drivers for the DataGlove. In addition, methodologies are being developed for mapping errors in the hardware and environment (i.e., the steel-reinforced concrete floor in the lab affects the magnetic field of the 3Space tracker) to produce a more consistent data stream. These drivers have been collected into a software library. Currently, we are in the process of writing a user's manual.

#### **Publications Resulting from This Research**

None reported.

### **[186] Design and Implementation of an Interactive Robotics Programming Environment**

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**Sponsor:** *Nemours Foundation*

**Purpose**—Both research and clinical applications work in the field of rehabilitation robotics is hampered by the absence of reliable, extendable, standardized programming tools and a comprehensive programmer development system with which to conduct the work. There are over two dozen rehabilitation robotics research programs in existence throughout the world today.

Although several are basic research groups and technically oriented, the majority of the projects are clinical in nature and have developed a technical component only as a by-product of the specific needs of the project. For example, there are projects researching various educational applications of a rehabilitation robotics system. Each of these programs has found itself struggling to develop working applications for research purposes and has developed a technical team whose focus is this development. As a result, much of the technical develop-

ment is application-specific. This is further aggravated by the fact that the groups are widely disparate in their choices of software and hardware. A variety of robots (RTX, Puma, Scrobot, Microbot, Alpha, Excalibur), and a variety of programming languages (C, Pascal, VAL II) are being used.

Thus, exchange of results can occur on a conceptual level, but working systems can rarely be exchanged from research program to research program. Further, as new robots are developed and existing robots are upgraded, much work is lost and much more needs to be completely revised in order to change to a new or upgraded machine.

This project proposes to design and develop the standardized software interfaces for both user/computer and computer/robot control. In addition, available programming utilities will be evaluated to establish their applicability to the rehabilitation robotics field. Unavailable but necessary utilities will



be designed and developed. The project will develop a standardized robot-control library and implement this model on the RTX manipulator.

**Progress**—Preliminary work on the development of the library has included creation of a design environment, development of a structure/hierarchy defined by compatibility concerns, and implementation of a prototype library.

The initial design of the robot library component has been completed and the library is 75 percent implemented on the RTX from Universal Machine Intelligence (UMI). The library design is based on a review of existing robot languages including VAL, CALVIN and CURL. Current efforts are centered on improving the accuracy and reliability of the interpolation algorithms. Two prototype object management libraries have been written; user's guides are currently being written.

**Future Plans/Implications**—Continuation of the project in the coming fiscal year will include a

development of manuals/documentation and further refinement of the library code. This prototype library will then be field tested at no fewer than four clinical/research sites, including the A.I. duPont Children's Hospital. In addition, a series of input-device interfaces will be developed, including DataGlove, keyboard, and several other devices developed in collaboration with the University of Delaware Rehabilitation Engineering Center in Augmentative Communication.

In succeeding years, additional robots will be implemented to test the portability and transferability of the concept.

#### Publications Resulting from This Research

**CALVIN: New Perspectives on a Robot Language.** Gilbert M, Minneman S, Pham T, in *Proceedings of the 10th Annual RESNA Conference*, San Jose, CA, 802-804, 1987.

**Development of a Programming Environment for Rehabilitation Robotics.** Gilbert M, Caruso J, Mahoney R, Fee J, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 377-378, 1989.

## [187] Mobile Rehabilitation Robotics

**Simon P. Levine, PhD; Johann Borenstein, PhD; Yoram Koren, PhD; Spencer L. BeMent, PhD; Lincoln A. Jaros, BS; Ulrich Raschke, MS; Thomas E. Pilutti, MS**

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University of Michigan, Robot Systems Division, Ann Arbor, MI 48109-2110

**Sponsor:** *University of Michigan Medical Center*

**Purpose**—The Mobile Rehabilitation Robotics Project, a joint venture between the Rehabilitation Engineering Program at the Medical Center and the Robotics Systems Division in the College of Engineering, is involved in the development of an intelligent, autonomous mobile robot. The goal is to develop a truly independent mobile robot that can not only pass from one point in its environment to another while avoiding random obstacles, but also follow or guide an individual to a desired location. Such a robot will be able to carry a variety of environmental manipulators such as robotic arms, environmental control units, or other assistive systems (including a computer-based functional task guidance system developed within the University of Michigan Department of Physical Medicine and Rehabilitation).

**Progress**—Previous work has been performed in the University of Michigan Robotics Laboratory on autonomous navigation algorithms for mobile robots in hazardous environments. These algorithms have been implemented and tested on a modified Cybermation K2A mobile robot. The work completed in the past year has consisted of preparing a Denning DRV-1W Mobile Robot for technology transfer from the Cybermation. A key element in this preparation has been to replace the standard Denning host computer, based on a Motorola 68000 processor, with an Intel 80386 host computer. The 80386 host computer significantly increases computing power while providing the same computing environment that exists on the Cybermation.

This work has entailed the development of a communication interface between the Denning robot



and 80386 host computer. This communication link transfers all information to and from the robot including ultrasonic range sensors, infra red position sensors, and motor controllers. This communication link has been designed to allow parallel data transfer on multiple channels. Interrupt-driven software algorithms combined with specialized communication hardware allow for maximum data flow.

**Future Plans/Implications**—We plan to further develop the autonomous mobile robot base for rehabilitation applications. Our objective is to develop the three basic components of an intelligent, autonomous mobile robotic base for use as an assistive system by: 1) implementing obstacle avoidance algorithms previously developed on the Cyber-mation mobile robot; 2) developing a companion tracking system capable of operating in both “lead” or “follow” modes; and, 3) developing global travel

and absolute positioning capabilities for operation in large, complex environments.

Completion of this project will enable the mobile robot base to approach the functionality of a truly independent unit that can not only pass from one point in a complex environment to another while avoiding obstacles, but also follow or guide a “companion” to a desired location.

### Publications Resulting from This Research

**Mobile Robot System for Rehabilitation Applications.** Levine SP, Borenstein J, Raschke U, Pilutti TE, Koren Y, BeMent SL, Kirsch NL, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 185-186, 1989.

**Semi-Autonomous Mobile Robot Platform for Rehabilitation Applications.** Levine SP, Borenstein J, Pilutti TE, Raschke U, Koren Y, BeMent SL, Kirsch NL, in *Proceedings of the International Advance Robotics Programme First Workshop on Domestic Robots and Second Workshop on Medical and Healthcare Robotics*, 15-18, 1989.

## C. Communication Methods and Systems

### [188] Augmentative Communication for Intensive Care Unit Patients

**Lewis P. Goldstein, PhD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C563-RA)

**Purpose**—The inability of intensive care unit (ICU) patients who are intubated and unable to verbally communicate has been identified as a major stressor. Incorporating communication aids into the ICU for intubated patients presents a challenge. Bedsides are already cluttered with equipment, patients are frequently restrained to prevent removal of lifesaving tubes and catheters, and activity is frequent and hurried. Furthermore, the patients are critically ill, often in pain, medicated, and frightened.

The *Intensive Care Communicator*, developed by Kevin Neelands in 1986, was designed solely for patients in ICUs. During the past 14 months, this augmentative communication computer program has been piloted in a medical and surgical intensive care unit. This computer program allows intubated patients to select words and phrases from a computer

screen word list to communicate wants and needs to nurses, families, and physicians. Initial findings indicate the capability and need for the communicator program for selected patients. Further research is needed to modify the word lists and to test modifications of the hand control device.

The major objective of the research is to continue testing and adaptation of the augmentative communication computer program, and seek answers to the following questions: 1) Can a tool be developed that measures the cognitive, motor, and sensory skills necessary for ICU patients to use the augmentative communication computer program? 2) Can word lists and phrase lists for the augmentative communication program be adapted to simplify patient selection of wants and needs? 3) Can preoperative teaching of postoperative ICU intubated patient candidates decrease training time



and patient stress, and increase quality of life during the noncommunicative period? and, 4) Can improved switch devices increase ICU intubated patients' communication with the augmentative communication computer program?

#### **Publications Resulting from This Research**

None reported.

### **[189] Trace Transparent Access Module (T-TAM) for Apple and IBM Computers**

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University of Wisconsin-Madison, Madison, WI 53705

**Sponsor:** *Office of Special Education Programs, Department of Education*

**Purpose**—Certain people with physical disabilities cannot operate standard input devices for commercially available computers. Many of these individuals can, however, operate a special communication or computer access aid, using a control system such as an optical headpointer or single switch. The aid in turn can be interfaced to the computer and used as an input device.

In the past, Keyboard Emulating Interfaces (KEIs) have been used to connect an aid to a computer. However, newer models of computers require the use of other standard input devices, in particular the "mouse"-type of pointing device. Thus, the computer user must be able to use the mouse (or equivalent) to operate the computer. This requires a General Input Device Emulating Interface (GIDEI), not just a KEI.

**Methodology**—The goal of this development effort is to create a commercially viable design for a GIDEI for Apple Macintosh, Apple IIGS, and IBM PS/2 computers—all of which use a mouse as a standard input device. This particular GIDEI has been named the Trace Transparent Access Module (T-TAM), since it provides "transparent" access to standard commercially available computer systems.

The T-TAM is a hardware module that translates standard serial ASCII code output from a

communication or computer access aid into the keyboard and mouse input signals required by the computer. In order to accomplish the function of a key or a mouse movement, the user sends a single ASCII character or string of characters to the T-TAM. According to the definitions set down in the GIDEI standard, the T-TAM converts the ASCII string to the correct keyboard or mouse input signal.

The T-TAM can be interfaced to Apple IIGS, Macintosh SE, and Macintosh II computers, as well as IBM PS/2 computers and IBM PC AT computers (with adapter).

**Progress**—Hardware design for the T-TAM is completed. Circuit boards have been manufactured for use in prototypes. Ten prototypes have been assembled for testing by interested manufacturers. A beta test version of the manual has been developed as well. Testing of the device and manual took place in October of 1989.

**Results**—The T-TAM is to be transferred to interested commercial vendors for manufacture and marketing.

#### **Publications Resulting from This Research**

None reported.

## **[190] Selecting Access Systems for Individuals with Physical Disabilities**

**Kathy Lee, BScOT, OT(C); Debra J. Thomas, BScOT, OT(C); Morris Milner, PhD, PEng, CCE; Penny Parnes, BSc, DSPA**

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**Sponsor:** IBM Corporation; IBM Canada Ltd.

**Purpose**—This research seeks to develop a clinical resource manual for the systematic assessment of alternate access methods for people with physical disabilities. This will assist clinicians in making well-informed decisions regarding the prescription and personalization of access systems for their clients. More carefully chosen access systems will give people with disabilities better control of computer-based technology.

**Results**—The research team has prepared a manual detailing a procedure for clinical assessment. By following the procedure, clinicians can determine the most appropriate access systems to enable their clients to control computer-based technology. The procedure addresses the needs of people with primary motor disabilities such as cerebral palsy, spinal cord injury, amyotrophic lateral sclerosis, and muscular dystrophy. Sensory and cognitive impairments affect the assessment only when they co-occur with motor disabilities.

The assessment procedure is comprehensive. Clinicians begin by investigating their clients' needs and abilities in many areas including medical, communication, mobility, education, vocation, and independent living. These needs and abilities, in turn, determine if a client needs access to technology. For those who do, clinicians assess physical

control in order to choose appropriate access systems. The procedure follows nine stages from the initial referral to the final installation of an access system in a client's home community.

This assessment procedure has four unique features. First, it works for clients who wish to control a wide range of computer-based technology by investigating their needs for different target systems as well as input devices. Second, the procedure's nine-stage structure is distinctive. As a third feature, the assessment procedure provides decision criteria at various stages to help clinicians identify which options will best meet their clients' needs and abilities. It highlights critical issues and supplies guidelines for interpreting the information gathered. Fourth, the procedure's designers anticipate that it will remain applicable despite changes in technology. The assessment guidelines contain general principles that refer to specific hardware and software for illustration.

### **Publications Resulting from This Research**

**An Assessment Protocol for the Selection of Access Systems for Persons with Physical Disabilities.** Lee K, Thomas DJ, Balfour L, Parnes P, in *Proceedings, ICAART 88*, Montreal, 6-7, 1988.

**Control of Computer-Based Technology for People with Physical Disabilities: An Assessment Manual.** Lee K, Thomas DJ, Toronto: University of Toronto Press, 1989.

## **[191] Computer-Based Technology for Individuals with Physical Disabilities: Guidelines for Alternate Access System Developers**

**Morris Milner, PhD, PEng, CCE; Penny Parnes, BSc, DSPA; Kathy Lee, BScOT, OT(C)**

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**Sponsor:** IBM Corporation; IBM Canada Ltd.

**Purpose**—Our purpose was to develop guidelines to assist in the design of future alternate access systems

for computer-based technology for a wide range of users.



**Methodology**—During a 3-year Shared University Research Project, researchers at the University of Toronto and the Hugh MacMillan Medical Centre reviewed a wide variety of computer access techniques. The team consolidated related clinical and technical knowledge in a set of guidelines to assist developers in the design of future alternate access systems for computer-based technology. The term “access system” refers to the hardware and software components that enable a person to interact with a computer, and the methods and processes involved in the interaction. It is distinct from the target system, which is the computer-based technology to which the user has access. An alternate access system incorporates components other than the standard configuration typically used with a computer.

**Results**—Twenty-two guidelines for the design of alternate access systems have been proposed. The guidelines are primarily based on the experience of clinicians who work with disabled persons and computer technology. If developers follow these guidelines, future alternate access systems may be more useful to people with disabilities. It is important to note that the guidelines are intended as guiding principles—they are not to be interpreted as rules or standards.

The guidelines are organized under the following headings: Input, Output, Selection Techniques, Setup and Configuration, and Target System Connection. Input guidelines deal with handling the raw data which the user supplies. This involves capturing, translating, and filtering the information so that other components of the alternate access system can

process it and send it to the target system. Output guidelines cover the presentation of information to the user. In addition to the target system, each component of the access system may generate feedback which must be conveyed to the user in a comprehensible form.

Selection technique guidelines deal with the way in which the user selects items of information for input to the target system. Setup and configuration guidelines cover the management of a flexible alternate access system including the definition of typical parameters such as key repeat time, delay time, scanning rate, volume settings, and filtering levels. The last set of guidelines deals with passing information between the target system and the access system.

**Future Plans**—The team has described a model for an ideal alternate access system incorporating the proposed guidelines. Subsequent research and development by the Microcomputer Applications Programme will follow the model and enhance it. Other developers have been encouraged to consider the guidelines in their designs of future access systems.

#### Publications Resulting from This Research

**Computer-Based Technology for Individuals with Physical Disabilities: A Strategy for Microcomputer Manufacturers.** *IBM Technical Report TR54.501*, Toronto: Hugh MacMillan Medical Centre, University of Toronto, 1988.

**Computer-Based Technology for Individuals with Physical Disabilities: A Strategy for Alternative Access System Developers.** *IBM Technical Report TR54.502*, Toronto: Hugh MacMillan Medical Centre, University of Toronto, 1988.

**Guidelines for Alternate Access System Developers.** Shein F, McDougall J, Knysh B, Sainani D, Lee K, Brownlow N, Milner M, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 19-20, 1989.

### [192] Computer-Based Technology for Individuals with Physical Disabilities: A Model for Access Systems

**Morris Milner, PhD, PEng, CCE; Penny Parnes, BSc, DSPA; Kathy Lee, BScOT, OT(C)**  
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**Sponsor:** IBM Corporation; IBM Canada Ltd.

**Purpose**—This project proposes a model for ideal computer access systems based upon guidelines developed in a previous project: “Computer-Based

Technology for Individuals with Physical Disabilities: Guidelines for Alternate Access System Developers.”



**Methodology**—As a basis for determining what functions and features an ideal access system should have, the project team evaluated various commercially available access systems. An analysis of translation processes between the user and the computer identified the functions common to all existing access systems, as well as the desirable features which current systems lack. Some systems are not flexible enough; it is not possible to tailor their functions to individual users. None of the access systems tested can adapt the output from a computer to accommodate different users' sensory modes.

**Results**—The proposed model translates information between a user and a target system through a framework of modules. Each module fits into the framework to perform one of the functions required for access. Developers can create new modules to meet particular needs and keep pace with advances in technology. The pool of available modules serves as a kit from which practitioners can assemble custom alternate access systems for individual users. This model resembles the user interface management

systems discussed in current computer science. An implementation of the model would have three components: 1) a "run-time" system with a managerial core to which modules are added, forming a complete alternate access system; 2) a configuration facility that enables the user or a helper to configure the run-time system; and, 3) a developer's toolkit for creating new modules.

**Future Plans**—As a structural standard, the model has practical implications for developers, practitioners, and users. The pool of available modules serves as a kit from which practitioners can assemble custom alternate access systems for individual users.

#### **Publications Resulting from This Research**

**Computer-Based Technology for Individuals with Physical Disabilities: A Strategy for Microcomputer Manufacturers.** *IBM Technical Report TR54.501*, Toronto: Hugh MacMillan Medical Centre, University of Toronto, 1988.

**Computer-Based Technology for Individuals with Physical Disabilities: A Strategy for Alternative Access System Developers.** *IBM Technical Report TR54.502*, Toronto: Hugh MacMillan Medical Centre, University of Toronto, 1988.

### **[193] Campus/Library Information Systems Accessibility Manual**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—There have been many computer access initiatives aimed at elementary and secondary special education students, both in and out of mainstream classes. By comparison, however, little has been done in post-secondary education (colleges and universities) and adult education (schools and public libraries) to assure that disabled people can access computers and information systems.

The gap will continue to widen as electronic information systems are used more and more extensively on campuses and in libraries. Among campus and library staff, there is a general willingness to provide computer access, but lack of knowledge and resources have been major obstacles. Information programs can provide a groundwork for acquiring the knowledge necessary to implement computer access. In addition, information can be provided

on how to maximally exploit any available resources.

**Methodology**—Initial information efforts have been targeted at university campuses. An *Accessibility Checklist* document is to be created and disseminated. This document will cover generic implementations of equipment—with steps delineated by time and money required to carry them out—and steps to be taken for individuals requiring more specialized equipment. An actual checklist form will be provided, on which staff can mark steps as they are implemented. The document will also provide a more thorough explanation of the steps involved, along with lists of additional resources to consult.

**Progress**—The *Accessibility Checklist* document was completed in draft form for distribution at the 1989



meeting of the Association of Handicapped Student Service Providers in Post-secondary Education (AHSSPPE). A finalized version of the *Checklist*, incorporating comments from potential users, will also be made available through the Trace Center Reprint Service.

**Results**—The goals of the *Accessibility Checklist* are: 1) to make it easier for administrators to plan and coordinate computer access efforts and to set priorities; 2) to provide a source of information and a common ground for planning for computer

sciences departments and disabled student services offices; and, 3) to provide a comprehensive reference for computer access needs and strategies. Other steps in the process of creating effective information materials include pilot evaluations of computer access programs at several universities and presentations to appropriate audiences at conferences.

#### **Publications Resulting from This Research**

**Maximizing "Bang-for-the-Buck" When Purchasing Adaptive Computer Equipment.** Berliss JR, in *Proceedings of the AHSSPPE 1989 Conference* (in press).

### **[194] Trace Center Database Development and External Feeding**

**Jane R. Berliss, AMLS; Gregg C. Vanderheiden, PhD; Peter A. Borden, MA; David P. Kelso, MS**  
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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The Trace Center maintains a number of ongoing information resources pertinent to communication, control, and computer access technologies. Over the past five years these resources have been converted to electronic database form. This has been done in order to facilitate response and referral, creation of publications, and uploads to other databases. The core databases (known collectively as "TraceBase") contain information on products, companies, publications, clinical service centers, networks and databases, self-help groups, organizations, and training programs. This data has been used to produce a number of publications. Recently, however, the center has examined distribution of the data in electronic form.

**Methodology**—Two main avenues of electronic distribution have been explored: 1) a user-friendly format that could be distributed on disk, tape, or

CD-ROM; and, 2) uploads of the data to other relevant databases.

**Progress**—A prototype version of a distributable TraceBase (Hyper-TraceBase) has been created. Uploads to six major databases have been carried out. These will be repeated on a regular basis. More uploads will be targeted and carried out as appropriate.

**Results**—Distribution of TraceBase in electronic form through these channels has broadened the availability of the information compiled at the Trace Center. The experience of uploading to different formats has provided information about how to make uploads more efficient.

#### **Publications Resulting from This Research**

None reported.

## [195] Cognitive Factors in Computer Access: State-of-the-Art Coordination and Planning Program

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Sponsor: *National Institute on Disability and Rehabilitation Research*

**Purpose**—Access to computers for people with cognitive impairments is a fairly new area of research; nonetheless, work has been done in this area, scattered across various disciplines and types of publications. In order to facilitate research at the Trace Center and at other centers interested in cognitive access, it was decided that a state-of-the-art report should be compiled, citing and summarizing current knowledge on the topic.

**Methodology**—The state-of-the-art reports are to cover four topics: 1) requirements for software and hardware design, including input mechanisms, displays, information content, and prompting; 2) requirements for computer task design; 3) procedures and principles of training in computer use; and, 4) selection of software and hardware features depending on specific aspects of impairment. In addition, the reports are to contain a bibliography of research on cognitive factors in access to computers and electronic equipment.

**Progress**—A literature review has been completed. This review provides the information for assembling the body of the report, and will also serve as the

bibliography for the report in its final form. The first and fourth sections of the report (Hardware/Software Requirements and Selection of Features) were completed in draft form, with the first section presented at the RESNA conference in June 1989, and the fourth section presented at the "Closing the Gap" national conference on computers and disability in October 1989. The second and third sections of the report (Task Design and Computer Training) were completed by the end of 1989. When the report is completed, it will be available from the Trace Center Reprint Service.

**Results**—The reports will serve as a resource to those wanting to improve the quality of interfaces for users with cognitive impairments, as groundwork for further research on this topic, and as input to design guidelines being prepared at the Trace Center.

### Publications Resulting from This Research

**Cognitive Factors Affecting Accessibility of Computers and Electronic Devices.** Cress CJ, Goltz CC, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 25-26, 1989.

## [196] An Augmentative Communication Software Architecture

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Sponsor: *National Institute on Disability and Rehabilitation Research; Nemours Foundation*

**Purpose**—The Architecture Project seeks to facilitate more cost effective development of Augmentative and Alternative Communication (AAC) application software by developing a general framework for describing AAC systems. The architecture will be implemented as a set of development tools that will allow other developers to produce new applications. This will effectively minimize duplication of efforts

in a field where resources are precious and promote sharing of ideas and software among developers. The objectives of the architecture project are as follows: 1) to develop an architecture that will support a wide range of AAC capabilities; 2) to develop a module library that supports the architectural components; and, 3) to develop an application that demonstrates the architecture.



This project is possible largely because of recent advances in software engineering. The use of object-oriented programming and design allow the construction of reusable software modules that can be shared among developers.

**Progress**—There are currently three major project phases underway:

*Needs Analysis.* The primary focus of the Needs Analysis Phase has been the development of a AAC technology needs survey. The goals of the survey are: 1) identify needs for future AAC systems; 2) prioritize those needs; 3) gain user perspective on specific design possibilities that we are considering; and, 4) encourage cooperation and inform people of this project. The U.S. membership of the International Society of Augmentative and Alternative Communication (ISAAC) was chosen as the target respondents. This society consists of a diverse group of individuals who are interested in augmentative communication. An initial mailing to 1400 people has recently been completed.

*System Requirements.* The System Requirements Phase is ongoing with its major product being the development of a systems requirement document. The systems requirements document will serve as a guide to the design and development of the architecture. The completion of this phase will follow the end of the Needs Analysis Phase in the winter of 1990.

*Design.* The Design Phase has recently begun. This phase will produce a detailed design document that will serve as the blueprint for the development of the architecture. In conjunction with the development of a paper-based design, we are also developing a prototype that will help us explore design ideas.

#### **Publications Resulting from This Research**

**The Development of a Software Architecture for Communication Systems.** Demasco PW, Ball JE, Kerly PJ, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 216-217, 1989.

### **[197] Development of Improved Headpointing Computer Access System**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—In 1981, the Trace Center began development of a optical headpointing input system for computers. The system was designed for use by persons who can easily aim at a target by moving their head, but who cannot effectively or quickly type keys using a finger, headstick or mouthstick. The user would point a small, light-weight cylinder towards an image of a keyboard displayed on a computer monitor. Pointing at the keys on the image would be equivalent to typing them on the standard keyboard. In this way the user could operate standard commercially available software on the computer.

The original commercially available version of the Long Range Optical Pointer (LROP) system required two monitor screens: one to display the keyboard image and one to display the application program. Feedback from users and from the manu-

facturer indicated that the two-monitor system put an undue burden on the user, requiring them to shift gaze from one monitor to another in order to operate the system. As a result, a "One-Screen" version of the LROP was developed.

**Methodology**—The One-Screen version of the LROP is compatible with IBM Personal Computers, using standard CGA graphics. The user switches from the keyboard image by briefly directing the pointer off the edge of the computer screen. The user can type a string of text or other characters on the keyboard screen, and elect to send this string to the application once they have decided the content is correct (this feature also was not present on the two-monitor system). The One-Screen version of the LROP also provides a prediction-based typing accel-



eration system, employing a list of 4,000 common words.

**Progress**—Development and commercial transfer of the One-Screen Version of the software for the LROP is complete.

**Results**—The product has been transferred to two manufacturers for distribution: Words+, Inc., of Lancaster, CA, and Pointer Systems, Inc., of Burlington, VT. Pointer Systems sells an infrared-

based pointer hardware system which will also work with the One-Screen software.

A manual for the One-Screen program has been developed, using the structured documentation approach also used in the documentation for the Trine communication system, developed at the Trace Center in 1984-85.

#### **Publications Resulting from This Research**

None reported.

### **[198] PC Transparent Keyboard for Headstick, Handstick, and Mouthstick Users with Voice-to-Text Mode**

**Everett Johnson; Adisak Mekittikul**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The advent of the personal computer (PC) has provided the severely handicapped person with the means of communicating, controlling their environment, and even gainful employment. The category of handicapped persons which this project addresses are those who, as the result of neurological impairment, cannot use a standard keyboard in the way for which it was designed. Persons with this type of handicap are restricted to activating the keyboard one key at a time, with a single digit, i.e., finger, handstick, mouthstick, or headstick. Various techniques, such as positioning templates, have been designed to improve the disabled person's use of a standard keyboard. The purpose of this project was directed toward designing a totally new keyboard which would use the abilities of the disabled person.

**Progress**—A 2-degree-of-freedom (2DOF) keyboard has been built. During the past year, modifications were added to allow the use of the keyboard, which was initially designed for the XT, with AT and PS/2 PCs.

*Summary of Special Features of the 2DOF Keyboard.* The keyboard has 90 physical keys arranged in 5 horizontal rows with 18 keys on each row. There are 4 keysets with 90 keys on each keyset which can be selected by any of the 4 keys at the 4 corners of the keyboard. These keys are referred to as "keyset-select-keys."

Each key, of the 360 available keys, can be assigned up to 16 characters. This means that up to 16 keystrokes on the regular keyboard can be assigned to a single key on the 2DOF keyboard, in the form of small phrases or parts of commonly-used words. The advantage of this feature is that it saves the number of key-hits required in order to type a word or phrase.

There are special functions that eliminate some of the problems that disabled people face in using the regular keyboard; such as the need to hit two keys at the same time (i.e., CONTROL key plus any other key, or SHIFT key plus any letter key). This problem is eliminated on the 2DOF keyboard by having special function keys that permit the CONTROL, SHIFT, and ALTERNATE keys to be selected as toggle keys. In addition, there is another special function key that, when selected, causes the first character of the next selected key to be shifted. Each key is a two-way action key, meaning that a key has to be initialized first and then selected before the character(s) assigned to that key are sent to the computer. This eliminates the problem of accidental selection of keys.

There is a 2-line-by-24-character display that gives information about the meaning and location of each key on the keyboard, and a speech circuit which can be operated in different speech modes. Every time a key is initialized or selected, depending



on the active speech mode, the speech circuit says the character(s) or phrase assigned to that key. Another speech mode allows the user to type up to 2,000 characters and have the speech synthesizer say the whole phrase collection at once.

The 2DOF keyboard can be used as a stand-alone communication device by making use of the display and the speech synthesizer. The meaning of each key is software-programmable, and the four

keysets can be easily customized for the needs of each individual user.

**Future Plans**—The keyboard is currently undergoing testing. All software, hardware design, PC-board layout, and four prototypes are complete.

#### **Publications Resulting from This Research**

None reported.

## **[199] Simulation of Alternate Computer Access Techniques and Operating System Hooks**

**Charles C. Lee, MS; Gregg C. Vanderheiden, PhD**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—In order to encourage computer and operating system designers to adopt “computer curbcuts”—simple adaptations to design that will accommodate users with disabilities—the Trace Center has created simulations and demonstrations showing how certain “curbcuts” can be implemented. Manufacturers are then able to see first-hand exactly what the design objective is, as well as gaining a comprehension of specific aspects of the feature or adaptation.

Simulations and demonstrations have been developed or conducted for design and project personnel at a number of computer companies. A 1-finger “sticky-keys” program developed at the Trace Center for the IBM computer line was used as a model by Apple for the StickyKeys feature which is now a standard accessibility feature in their Macintosh computer line.

**Progress**—Simulations of “1-Finger” and “Mousekey” features have been developed for demonstration to the IBM Corporation and Microsoft, Inc. (Microsoft is the developer of “Windows” software, a recently developed operating system environment for IBM microcomputers that utilizes graphics-based screens and graded input devices such as the mouse.) This demonstration has been developed for the

Windows 2.0 environment on IBM PS/2 computers.

The “1-Finger” feature allows modifier keys (such as SHIFT, CONTROL, and ALT) to be operated by single-finger, headstick and mouthstick computer users. The “Mousekey” feature offers the user an option of using keys on the keyboard to perform all functions of the mouse. (As a temporary measure for those needing the capability, IBM is also distributing the “1-Finger” program for the PC-DOS operating system developed by the Trace Center.)

**Results**—This implementation is being used to explore incorporation of the features in Windows 3.0 and OS/2 (although some of the systems issues are much complicated in these environments). Continued work on the Windows 2.0 implementations are planned in addition to release of the current revised version through the campus software distribution system, WISCWARE. This work will also be used as a jumping-off point for exploring access features in Windows 3.0 and OS/2.

#### **Publications Resulting from This Research**

**Access to Microsoft Windows 2.0 for Users with Physical Disabilities.** Lee CC, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 23-24, 1989.

## [200] Personal Computer-Based Augmentative Communication Systems

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**Sponsor:** *National Institute on Disability and Rehabilitation Research; Nemours Foundation*

**Purpose**—The purpose of this project is to develop new augmentative communication systems based on personal and portable computers. This approach was chosen for three reasons: 1) flexibility of the computer allows a system to be individually configured for each user; 2) PC-based systems allow new technology to be efficiently transferred to end users; and, 3) updates and modifications to the systems can be made more rapidly with software-based systems.

**Progress**—A PC-based communication system, named Meta4, has been designed for use with desktop or laptop computers that support MS-DOS. Some of the features of the system include a flexible, unlimited vocabulary, dynamic displays, abbreviation expansion, and multiple text editing windows. The system also supports various input devices (switch, mouse, joystick, or powerpad), output devices (speech synthesizers, printers, environmental control units), and input methods (scanning, directed scanning, and direct selection).

Two features that distinguish this system from commercially available products are its configurability and data collection capabilities. A menu-driven utility allows clinicians to specify the many adjustable aspects of the system. Using this utility, the clinician can adapt the system for a specific user. Changes in the configuration can be made at any time, allowing Meta4 to grow with the abilities of each user. The system also gives the option of

automatic data collection (usage tracking). With this feature, all selections made by the user are recorded and analyzed. This provides feedback to the clinician concerning the efficiency of the present system configuration. It is primarily intended for use with the vocabulary set and screen layout.

**Preliminary Results**—At this time, Meta4 is used as a functional communication device for one test subject. This subject uses Meta4 on a Toshiba laptop computer for daily communication needs. The system is currently configured for single-switch scanning and is operating in conjunction with a commercially available speech synthesizer, printer, and environmental control unit.

**Future Plans**—The primary system improvement will be the addition of graphics capability that allows variable height and spacing of text as well as incorporating symbols for nonreaders.

After this and other improvements are made, Meta4 will be evaluated in a clinical setting. Subjects will be instructed to perform a set of identical tasks designed to test many aspects of the overall system. Based on the results of this evaluation, Meta4 will be made available to manufacturers for further development as a commercial product.

### **Publications Resulting from This Research**

None reported.

## [201] Keyboard Emulating Interface (KEI) Standard

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**Joseph M. Schauer, BS; Gregg C. Vanderheiden, PhD; David P. Kelso, MS**  
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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Certain people with physical disabilities cannot use a standard computer keyboard to operate

a computer. Many of these people, however, can operate a specially-designed communication aid or



computer access aid, using some control mechanism such as a single switch or an optical pointer. The communication or computer access aid in turn can be used to control the computer by connecting the two via a Keyboard Emulating Interface (KEI).

Originally, KEIs were created individually for each model of communication aid. This, however, is not necessary, since most aids are capable of sending standard serial ASCII code. As long as a standard can be established for the conversion of serial ASCII into standard computer keyboard input codes, then the same KEIs can be used by any aid.

**Methodology**—The KEI Standard is treated as a working document, with each revision submitted to the field for comment. Past versions have been used as the basis for the design of commercially available KEI modules. The standard document provides the manufacturer of a KEI with all the information necessary to implement the standard in their device. In addition, Trace Center programmers have programmed KEIs in software: this can eliminate the need for a hardware KEI module for some computer models.

**Progress**—Version 1.1 of the KEI standard has been revised and submitted to the field for comment. The revisions include: 1) ability to change data transmission (baud) rate; 2) addition of new key names to accommodate new keyboards; 3) removal of some obsolete commands; and, 4) development of a new KEI Standard that will mesh with the new General Input Device Emulating Interface (GIDEI) standard.

**Results**—Currently, KEI standards exist for IBM PC, XT and AT computers and for Apple II series computers. Standards for IBM PS/2 and Apple Macintosh computers are being developed in conjunction with the GIDEI, because these computers employ another standard input device (the mouse) in addition to the keyboard.

#### **Publications Resulting from This Research**

**Keyboard Emulating Interface (KEI) Compatibility Standard.**  
Schauer JM, Kelso DP, Vanderheiden GC, Lee CC, Madison: University of Wisconsin, Trace Research and Development Center, 1988.

## **[202] General Input Device Emulating Interface (GIDEI) Standard**

**Joseph M. Schauer, BS; Gregg C. Vanderheiden, PhD; Charles C. Lee, MS**  
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University of Wisconsin-Madison, Madison, WI 53705

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Certain people with physical disabilities cannot operate standard input devices for commercially available computers. Many of these individuals can, however, operate a special communication or computer access aid using a control system such as an optical headpointer or single switch. The aid, in turn, can be interfaced to the computer and used as an input device.

In the past, Keyboard Emulating Interfaces (KEIs) have been used to connect an aid to a computer. However, newer models of computers require the use of other standard input devices, particularly the "mouse"-type of pointing device. Thus, to operate the computer, the user must now be able to use the mouse (or equivalent), in addition to the keyboard.

In order that KEIs can be standardized across

most communication and computer access aids, the Trace Center has developed and supported a KEI standard. To address the need for standard emulating interfaces for other input devices like the mouse, the Trace Center has begun development of a General Input Device Emulating Interface (GIDEI) Standard.

**Methodology**—The GIDEI Standard, to be developed as a document, will be circulated to concerned manufacturers and others in the field. Comments on the draft version are to be incorporated into a final version that will be used in the design of GIDEIs. The standard is "open": it is a framework within which other substandards can operate. This makes the standard flexible enough to accommodate other input devices that may need to be incorporated.



**Progress**—The initial GIDEI Standard is currently in development. This standard, the Trace Transparent Access Module (T-TAM), is being implemented in a hardware device designed at the Trace Center.

**Results**—The draft version of the GIDEI standard will be circulated for comment: the final version will be published. This version will be implemented in

the T-TAM as it is commercially transferred for manufacture and sale. The GIDEI standard will be sent to concerned manufacturers and made available to other interested parties through the Trace Center Reprint Service.

#### **Publications Resulting from This Research**

None reported.

### **[203] Simple Electrical Transducer (SET) Standard**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—In the past, a wide variety of connector types were used for the interconnection between user controls and electrical and electronic assistive devices for people with disabilities. Connections that were electrically similar to those of another product often used connectors that were incompatible with that product when compatible connectors could have been used.

In order to ensure greater compatibility between user interfaces and assistive devices, the Trace Center initiated a Simple Electrical Transducer (SET) Standard. The original SET efforts led to the adoption of a voluntary standard (SET Version 0.2). About 85 percent to 95 percent of controls and devices eventually conformed to it. During 1987-1988, a revision of the first standard was issued (SET Version 1.0), taking into account the suggestions and comments received from interested manufacturers, clinicians, researchers and users.

**Methodology**—The SET Standard seeks to standardize: 1) the physical connections between user controls and electrical/electronic aids; 2) the electrical specifications of the interfaces between controls and aids; and, 3) the categorization and labeling of controls and aids in accordance with their electrical makeup.

The standard is circulated in draft form among interested parties and published as a working paper.

The document version is distributed through the Trace Center Reprint Service. The document explains all aspects of the standard as simply as possible while still remaining accurate. Explanations employ text and diagrams. Appendices provide a quick reference to pin assignments for connectors.

**Progress**—During 1988-1989, a revision of SET Version 1.0 was undertaken. Version 2.0 was completed in draft form and sent out for comment. Some explanations have been revised and obsolete material has been dropped. A copy has been sent to the International Standards Organization (ISO) for possible inclusion in their electrical and electronic standards.

**Results**—Comments solicited on Version 2.0 will be integrated into the next revision of the standard. The ISO will be kept informed of future revisions, and information and support will be provided for any effort they make to adopt the SET.

#### **Publications Resulting from This Research**

**Simple Electrical Transducer (SET) Compatibility Standard.** Schauer JM, Kelso DP, Vanderheiden GC, Madison: University of Wisconsin, Trace Research and Development Center, 1988.



## [204] Computer Accessibility Design Manual

**Gregg C. Vanderheiden, PhD; Roger O. Smith, MOT, OTR; David P. Kelso, MS; Charles C. Lee, MS; Cynthia J. Cress, MS**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The Trace Center for several years has coordinated an industry/government cooperative effort directed toward improving the accessibility of computers to people with disabilities. One result of this effort has been a working document, *Considerations in Design of Computers and Operating Systems to Increase Their Accessibility to Persons with Disabilities*.

The document, although still being revised, has been received very well by the computer industries. At least two major computer manufacturers have incorporated (often verbatim) materials from the document in their internal company documents. Three major computer corporations are incorporating features and solution strategies in the guidelines of their future computers and operating systems.

**Methodology**—The existing guidelines have been designed using a U.S. mail based open task force approach. The task force is "open" in that anyone can join the group. Membership in the group is defined as those individuals who remain active. All communication is conducted by mail; electronic versions formatted for the major computer brands are available. As a result, individuals from different companies, geographic locations, or with different

disabilities, can all access and participate equally. This procedure has worked very well to date.

**Progress**—A new version of the manual (4.2) with extended discussion, data, and notes was completed and disseminated to the field for review. Adopted and adapted by two major computer companies, it was used in the final preparation of the GSA guidelines. Version 5.0, which will include cognitive disabilities for the first time, is in progress and should be completed and released in 1990.

**Results**—Dissemination of the manual (and intermediate results from this project) will be accomplished through the Industry/Government Task Force on Computer Accessibility, and through the Trace Center Reprint Service. These, combined with an open-copying policy, have resulted in excellent dissemination of materials to date, particularly within the computer companies.

### **Publications Resulting from This Research**

**Considerations 4.2: Results of the Industry/Government Cooperative Effort on Computer Accessibility for Disabled Persons.** Vanderheiden GC, Lee CC, Madison: University of Wisconsin, Trace Research and Development Center, 1988.

## [205] Guidelines for the Design of Consumer Electronic Products

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Different types of impairment can lead to restrictions in use of consumer electronic products or even render them unusable by people with disabilities. As with computers, there are simple design modifications that can be made in order to accommodate the needs of disabled people, without substantially adding to the cost of production or

inconveniencing other people who are not disabled.

The purpose of this project is to create a set of guidelines to be used voluntarily by designers and manufacturers. These guidelines will discuss the full range of needs of persons with physical, sensory and cognitive disabilities, and possible solutions. Not all will be low- or no-cost solutions, but these will be



suggested where feasible. The usefulness of certain modifications—such as location and ease of use for controls—to nondisabled consumers will be stressed.

**Methodology**—The guidelines will be treated as a working document that is sent out to consumers, researchers, and manufacturers for comment. These comments, along with additional material developed at the Trace Center, will be added to future editions.

**Progress**—A preliminary compilation of the guidelines is complete and a first draft of the document is being prepared. At the same time, a task force is being formed that is similar to one developed for the computer design considerations. Initial members of

the task force will include those individuals who have contributed to computer design considerations, as well as individuals who have expressed an interest in this topic to the staff of the Electronic Industries Foundation project on rehabilitation engineering. Other individuals and organizations will be able to join simply by expressing an interest and contributing ideas. The initial draft of the guidelines will be forwarded to the task force for review: it is expected that a first revised version should be available in early 1990.

#### **Publications Resulting from This Research**

None reported.

### **[206] Development of User-, Professional- and Public-Accessible Databases on Assistive and Rehabilitative Technology**

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University of Wisconsin-Madison, Madison, WI 53705

**Sponsor:** *National Institute on Disability and Rehabilitation Research; ABLEDATA, Newington Children's Hospital*

**Purpose**—There are a number of electronic databases which provide information on technology for people with disabilities. In the past, these have usually been made available in "on-line" form. Typically, these databases require that the person using them have experience in using computers, modems and databases; be familiar with a large vocabulary of key search terms; and be able to create effective Boolean logic search statements.

Trace Center staff and other experts in the field have been aware for some time that these requirements limit the number and variety of people who are able to access the information in on-line databases. Improved interfaces are clearly needed to make searching easier. In addition, improvements in data storage for personal computers have made it possible for very large databases to be stored directly on an individual microcomputer, eliminating the need to dial in via modem or incur connect-time charges.

**Methodology**—The first database development project of this type to be completed and released is Hyper-ABLEDATA. Hyper-ABLEDATA is a mi-

crocomputer version of the on-line assistive technology database ABLEDATA, maintained by the Newington Children's Hospital in Connecticut. The interface created at the Trace Center provides three distinct advantages: 1) the program runs on the user's own microcomputer; 2) the "point-and-click" interface does not require the user to be trained in how the system works; and, 3) the search routines have been greatly simplified, using an expanding outline format for the 4,000-term thesaurus (Boolean logic searching is also available, for more sophisticated users).

A number of other possible distributable databases are being examined. Once modified, these would be made available along with Hyper-ABLEDATA.

**Progress**—The version of Hyper-ABLEDATA currently available is for the Apple Macintosh. A version for IBM computers is now in development. The database is to be updated every 6 months. It is being made available on three different media: disk, tape, and CD-ROM (Compact Disk Read-Only Memory).



## Publications Resulting from This Research

**The Use of Hyper-Text in Distributable Databases for Personal Computers.** Vanderheiden GC, Borden P, in *Proceedings of the National Symposium on Information Technology*, Charleston, SC, 1989.

**Hyper-ABLEDATA.** Vanderheiden GC, Kelso D, Hinkens JD, in *CO-NET*, 1st ed. (Compact Disk ROM). Madison: University of Wisconsin, Trace Research and Development Center, 1989.

## [207] Speech Synthesis Program

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**Sponsor:** *National Institute on Disability and Rehabilitation Research; Nemours Foundation*

**Purpose**—The purpose of this program is to create high quality, unrestricted, multilingual synthesized speech in a number of different voices.

**Methodology**—This program can be partitioned into four projects. These are: 1) development of a software diphone synthesizer; 2) development of an automatic diphone extractor; 3) generation of a bilingual speech synthesis system based on English and Spanish; and, 4) production of a hardware speech synthesizer.

The software synthesizer will use diphones as its units of synthesis because diphones allow unrestricted vocabulary while providing high quality, intelligible speech. Diphones are speech segments that run from the steady state of one phoneme to the steady state of another, capturing the transition between phonemes. The diphones are recorded in carrier words and then manually extracted and stored. The process of creating a complete library takes approximately 6 months.

Once the library has been completed, it must be used in conjunction with an algorithm that converts written text to synthesized speech. This algorithm is used in conjunction with an algorithm that partitions text into syllables with stress markers. With this information, pitch contours can be imposed upon the synthesized utterance. This will increase its intelligibility and naturalness.

In order to create a synthesizer that allows the voice of choice, an automatic diphone extractor must be developed. The automatic extractor will use an original library for template matching, plus rules based on the spectral analysis of the recorded

speech. With it, a nonvocal person will be able to choose the voice and dialect with which he/she wishes to communicate.

To further extend the population of nonvocal users, a bilingual speech synthesizer will be developed. First a library of Spanish diphones will be generated, then a Spanish text-to-speech algorithm will be created. Along with this, rules for imposing Spanish pitch patterns on synthesized utterances will be developed.

The final subproject is the development of a hardware speech synthesizer. This hardware synthesizer must be portable, lightweight, flexible, and efficient.

**Preliminary Results**—At this point, a library of diphones in a female voice is being generated. The American English text-to-speech algorithm has been completed, and the syllabifier is well underway. Methods for imposing pitch contours have been developed, and the resulting speech is clear and natural sounding.

The automatic extractor functions well with a number of phonemic combinations. Speech created from diphones that have been automatically extracted sounds intelligible and smooth.

**Future Plans/Implications**—Future plans include the manual creation of diphone libraries in a male and a child's voice, the completion of the automatic diphone extractor, the development of a bilingual speech synthesizer, and the production of the hardware diphone synthesizer.

**Publications Resulting from This Research**

**New Methods for Pitch Change During Time-Domain Waveform Coded Diphone Speech Synthesis.** Yarrington D, Jones M, Foulds RA, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 220-221, 1989.

**The Synthesis of High Quality, Human Sounding Speech.** Yarrington D, in *Official Proceedings of Medical Applications of Voice Response Technology*, Pittsburgh, PA, 1989.

**[208] Remote-Controlled Communications and Control Unit**

**John A. Konotchick**

KAB Laboratories, Inc., San Diego, CA 92122

*Sponsor: National Institute of Child Health and Human Development, National Institutes of Health*

**Purpose**—The purpose of this research is to develop a complete functional unit with which a wide variety of communications and control aids can be made available at low cost to individuals with impaired mobility. The unit would permit remote control of electrical devices, intercoms, telephones, and door locks. If successful, this unit would provide an

inexpensive means for better communications, offer a greater control over the environment, and present an added measure of safety.

**Publications Resulting from This Research**

None reported.

**[209] Telephone Interaction for Handicapped Individuals Using a Remote-Controlled Device**

**John H. Stokes**

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*Sponsor: National Institute of Child Health and Human Development, National Institutes of Health*

**Purpose**—The general problem is to develop an inexpensive remote-controlled device which provides for rapid access to communication with others—specifically through the telephone. The device will allow a handicapped individual with little capability for movement to operate a telephone through a series of eyeblinks.

This proposal offers a systematic approach to developing a practical product based upon the application of infrared electro-optics.

**Publications Resulting from This Research**

None reported.

**[210] An Accessible Computer Workstation and School Desk for Use in the Classroom**

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*Sponsor: Ontario Ministry of Education; Hugh MacMillan Centre School and Hugh MacMillan Medical Centre*

**Purpose**—The purpose of this project is to work toward developing a fully accessible workstation and school desk that will accommodate both the educational and therapeutic needs of physically disabled students within the school classroom. Specific goals

are to: 1) design and develop an accessible work surface that will meet the needs of a variety of students in a classroom setting; and, 2) assess the performance of the basic unit through a number of placements in the school.



Commercially-available computer tables generally do not facilitate access, nor do they promote proper positioning of the physically disabled student. Most tables are designed to be used by one individual in a home or office setting; therefore, they are often not readily adjustable, if at all. This type of table is impractical in the classroom where many students having unique special needs may be required to use the same computer each day. In response to this, a multidisciplinary team from the Hugh MacMillan Medical Centre and the Hugh MacMillan Centre School has undertaken a project to develop a fully accessible computer workstation and school desk that will accommodate both the educational and therapeutic needs of physically disabled students within the school classroom.

**Progress**—A modular workstation was conceived to satisfy the broad range of needs of students with physical disabilities. Such an approach would permit the appropriate components to be assembled and adjusted to match individual needs. The foundation of the design is an adjustable work surface which can accommodate the basic hardware (computer, monitor, keyboard, and disk drive) as well as a workspace for a textbook or other material. Other modular components would build onto this basic unit, permitting greater flexibility in positioning equipment, providing forearm support, and accommodating alternative interfaces, remote keyboards, and a printer.

## **[211] Mobility Training and Evaluation for the Home and School Environment**

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**Sponsor:** *Ontario Ministry of Health; Toshiba of Canada Ltd.*

**Purpose**—A client's cognitive inability to control the movements of a powered wheelchair has two possible consequences: 1) the person returns home without a powered chair and may be asked to come back in 6 or 12 months for a reassessment; or, 2) the person is enrolled in an individually designed powered wheelchair training program and learns to drive a powered chair. After successfully completing a training period of variable length, the client attains

The basic unit is constructed of 2-inch diameter steel tubing. The base, mounted on castors, is a U-shaped configuration with the open end facing the user. A pedestal mounts centrally at the rear of the base and houses the mechanism for adjusting the height from 24 to 32 inches. This configuration facilitates access to the work surface by children in wheelchairs, as well as those using braces, crutches, and canes.

Cantilevered from the pedestal is a small tubular frame, also U-shaped. The work surface is hinged at its midline by a tilting device mounted on this upper frame which permits angle inclination from flat or horizontal to a tilt of 22 degrees. The work surface is three-quarter-inch plywood laminated with matte-grey arborite.

**Preliminary Results**—The prototype basic unit was assessed by teachers, teaching assistants and a therapist over four 3-week trials. Results of the evaluation indicated that the basic unit performed favorably.

**Future Plans**—It is evident that development of other modular components is needed to complete the computer workstation. Work is presently underway to develop a production version of the basic unit.

### **Publications Resulting from This Research**

None reported.

independent mobility. There are very few training programs, and the time and labor which the training requires greatly limits the capacity of the program. Most cognitively low-functioning clients therefore leave the assessment clinic with a request to return months or years later. Without a means of independent mobility, these people stand very little chance of eventually acquiring the skills necessary to operate a wheelchair. Their immobility diminishes their



opportunities to learn other important cognitive, social, and perceptual skills necessary to drive a powered wheelchair safely.

This project aims to develop a simple microprocessor-based training and evaluation package which can be used in the home, residence, or institution. It will allow a person to learn to use a control system (5 switches or a joystick) appropriate for driving a powered wheelchair. The unique features of this project include: 1) a labor-intensive training and evaluation program that is transferred from the health care institution to the home or residence environment; 2) a training and assessment package that requires little of the caregiver beyond plugging it into the nearest power outlet; 3) data collection

and adaptation of the program that can be performed either in the home, via a modem link to the training module, or at the Hugh MacMillan Medical Centre during an assessment visit; and, 4) training and assessment programs that are geared to cognitively low-functioning and/or physically disabled individuals.

**Future Plans**—We plan to use portable microcomputers to facilitate the collection and communication of data between the participants' homes and the Hugh MacMillan Medical Centre.

#### **Publications Resulting from This Research**

None reported.

### **[212] Microcomputers in Special Education for Children with Communication Problems**

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**Sponsor:** *Tayside Region Education Department; Scottish Education Department; Department of Trade and Industry*

**Purpose**—The aim of this project is to investigate how current technology can help with the problems of children with special educational needs, particularly those with speaking and writing difficulties. The project is closely linked with other research work in the Microcomputer Centre and a major part of the research team's mission is to consider the application of Predictive Adaptive Lexicon (PAL) within a school environment and assess it in the classroom.

On the basis of this assessment, versions of this system will be designed specifically for the educational environment and evaluated within local schools.

**Progress**—In order to take full advantage of the software in an educational setting, an investigation of the required additional features was conducted. Major requirements were: large character mode to assist reading the screen, spelling help over and above that offered by PAL, and nonkeyboard entry.

The work to date has concentrated on assisting children with physical handicaps experiencing writ-

ing difficulties; children with cerebral palsy and muscular dystrophy are being initially investigated.

Single-case studies of the children involved with the research have been initiated and the program has been evaluated by teachers, speech therapists, and the users.

It has become obvious that physical disability was not the only issue as the children also presented with classic learning difficulties. After using PAL for a few weeks they became more aware of their own spelling problems and looked at the predictions for assistance. The project was extended to children with specific learning difficulties.

**Future Plans**—Future plans include implementation of a spelling helper and a speech synthesis system. Long-term development is towards using PAL in mainstream schools to assist children with specific learning difficulties.

#### **Publications Resulting from This Research**

None reported.



## [213] Applying Artificial Intelligence Techniques to a Personalized Communication Aid

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Sponsor: *TSB Foundation for Scotland*

**Purpose**—The objective of this project is to investigate the potential of artificial intelligence (AI) techniques in a computerized communication aid. The work to date has concentrated on reviewing the fields of augmentative and alternative communication and the aspects of AI which are relevant to this field. The intention is to use existing AI techniques such as knowledge representation and natural language processing systems to produce a practical device. From this, a prototype has been developed that is about to undergo a 12-month case study with a nonspeaking subject.

**Methodology**—The design objective is to create a communication shell or tool kit, which can be used to capture the user's individual communication needs, and will be easy and fast to use. The system will contain a database of speech utterances which will be created with the user. These may be reused or modified syntactically to suit changing requirements. If a suitable utterance is not found, one can be added to the database; the user will also be able to input utterances in preparation for a conversation.

Knowledge representation techniques have been used to represent knowledge about the user and key conversational partners as well as specific situations the user wants to deal with. This knowledge is used

to search the database of situation. The user is presented with a choice of five possibilities and the option of extending the search. In addition, we are experimenting with using knowledge of speech acts both to help create the database of utterances and to search it for suitable output.

The case study is designed to advance the development of the system both by testing the prototype and developing strategies applicable to the user environment. Assessment of the subject's language and communication skills will be made before and after the case study. Conversations will be monitored and analyzed to test potential system developments. The system will be evaluated by the user, conversational partners, and speech therapists.

**Future Plans**—Future developments include generalizing the communication shell or tool kit structure so that it can be used by others. This will mean creating an "empty" communication aid which would be filled by the user's utterances and relevant knowledge. The longer term development is toward using both the structure and user's knowledge in a communication aid which will generate utterances.

### Publications Resulting from This Research

None reported.

## [214] Modeling of Performance with Computer Access and Alternative Communication Systems

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Sponsor: *University of Michigan Medical Center*

**Purpose**—This project explores the use of a technique for modeling the user interface of augmentative communication and computer access systems. The short-term goal of this work is to provide both developers and clinicians with a framework that can

improve the development and prescription of alternative access systems. The long-term goal is to use the model to quantitatively predict user performance with these systems and simulate a large range of user and system characteristics. The modeling process



also offers a valuable qualitative analysis because it provides the opportunity to carefully analyze the interaction between the user and an alternative access system under a wide range of conditions.

**Progress**—A modeling technique which is used extensively in the field of human-computer interaction, called the GOMS model (Goals, Operators, Methods, Selection Rules), has been chosen for this work. This model provides a comprehensive description of user performance based on system-specific parameters as well as the cognitive, perceptual, and motor capabilities of the user. It can be used to predict both learning and performance times, as well as points of excessive long- or short-term memory load.

Three interfaces currently used in augmentative communication and computer access systems have been modeled using the GOMS technique in order to quantitatively describe and predict user performance. The modeled interfaces are: 1) row/column letter scanning; 2) row/column letter scanning combined with word prediction after the first two-letter selections only; and, 3) row/column letter scanning combined with word prediction after each letter selection.

**Preliminary Results**—The primary outcome of the modeling is a set of equations which can be used to predict performance time for each interface. Nomi-

nal input parameter values were determined and used for model simulations. Sensitivity analyses were also performed using a range of values for particular input parameters. Results for the three systems modeled here suggest the possibility that word prediction interfaces, developed as a faster alternative to row/column letter scanning, may actually be less efficient than letter scanning in some situations. The modeling process also provides estimates of learning time and short-term memory load. No substantial difference in these two characteristics was predicted among the three interfaces.

**Future Plans**—The validity of these results is dependent upon the accuracy of the GOMS models. Therefore, a primary direction for future research is to study the behavior of actual users with a variety of alternative access methods and compare it with GOMS model predictions. Refinement of model descriptions and input parameters can then be made to improve model accuracy.

#### **Publications Resulting from This Research**

**Modeling of User Performance with Computer Access and Augmentative Communication Systems for Handicapped People.** Horstmann HM, Levine SP, in *Proceedings of the 11th Annual Meeting of the Cognitive Science Society*, Ann Arbor, MI, 659-666, 1989.

**GOMS Modeling of Performance with Computer Access and Augmentative Communication Systems.** Horstmann HM, Levine SP, *Augment Alternat Commun* (in press).

### **[215] Guidelines for the Requirements of Computer-Based Systems to Accommodate Direct Manipulation as a Means of Alternate Access**

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**Sponsor:** *University Research Incentive Fund of the Ontario Ministry of Colleges and Universities; IBM Corporation; IBM Canada Ltd.*

**Purpose**—This project will investigate control of computers by people with severe physical disabilities by examining and assessing various alternative access techniques in a direct manipulation environment. Direct manipulation environments are a type of computer-user interface where the user controls computer processes by manipulating analogous representations on the screen display. Current direct manipulation environments combine a graphically-

oriented display with a pointing device such as a mouse. Although many able-bodied people find it powerful and intuitive, direct manipulation can make impossible demands on a user with a severe physical disability. In this project we will propose and clinically evaluate both software and hardware solutions to overcome the obstacles that direct manipulation presents.



**Methodology**—A research therapist will conduct a series of clinical trials in which people with severe physical disabilities perform various direct manipulation tasks on a computer. For the tests, the project team will develop a software clinical trial environment incorporating different access techniques. The trial participants will have had some experience with nondirect manipulation computer systems. Their current access device will be some form of keyboard including alternate keyboard systems. Within this project, participants are classified as Group A or Group B. Group A users are “Typers”: they can type with a single digit (using a single finger or holding a pointer), or with a mouthstick or a headpointer, but cannot use a standard mouse. Group B includes two classes of users who are unable to use a physical keyboard and require a “visual keyboard.” The first category are “Pointers” who have continuous control and can directly point (usually with a headpointer, sonic, infrared, or long-range light). The second are “Scanners” who have binary (on/off) control and must use some form of scanning (automatic, directed, step, or inverse).

**Progress**—This 2-year project is currently midway. A variety of pointing devices including mouse,

trackball, joystick, touch tablet, and infrared headpointer (FreeWheel™, Pointer Systems, Inc.) have been evaluated and problems associated with their use have been documented. Modifications to the devices or the manner in which they are used have been suggested and tried. The next step is to evaluate software modifications to the standard Windows™ environment. Here, we propose to rewrite the illusion of a direct manipulation interface. Interfaces that match the abilities and experience of the user will be programmed and evaluated. The standard desktop metaphor, for example, may not be appropriate for someone unfamiliar with office work or unable to manipulate such objects in the real world.

#### Publications Resulting from This Research

**Direct Manipulation: Its Significance for People with Disabilities.** Brownlow N, Shein F, Thomas D, Milner M, Parnes P, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 244-245, 1989.

**Direct Manipulation: Problems with Pointing Devices.** Brownlow N, Shein F, Thomas D, Milner M, Parnes P, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 246-247, 1989.

**A Model for Alternate Access Systems.** Shein F, McDougall J, Knysh B, Sainani D, Lee K, Brownlow N, and Milner M, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 17-18, 1989.

## [216] Computer Interpretation of Gestures Made by the Severely Disabled

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Sponsor: Microcomputer Centre; Winston Churchill Travelling Fellowship

**Purpose**—Our purpose is to investigate free arm movement or gestural control of computer-based aids by the severely disabled. People with severe disabilities have problems producing discrete movements (e.g., hitting a switch) or serial movement tasks (e.g., pointing) necessary for the control of computer-based aids. In an attempt to overcome these problems, we intend to harness the repertoire of arm movements (or gestures) available to a particular subject. Computer recognition of the different gestures available to each subject will allow the control of computer systems via gestures and remove or reduce the problem inherent in some

conventional input systems (e.g., targeting on a switch).

**Progress**—A commercially available position monitoring system is being used to monitor arm movements. Programs have been developed to allow gesture data collection and storage on disk for subsequent analysis, display of movement data with manual segmentation of such data into gestures, and derivation of velocity and acceleration from the original displacement data. Gesture data has been collected from a number of disabled subjects.

**Future Plans/Implications**—Work has now begun on the development of a gesture recognition system. This will involve the preprocessing of the data, automatic segmentation of the data into gestures, and classification of each gesture. This research should lead to an alternative method of input to computer-based aids in which the repertoire of free

arm movements available to a disabled person can be used for input to, and control of, computer-based devices.

#### **Publications Resulting from This Research**

None reported.

## **D. Private/Public Programs**

### **[217] Secondary Disability Prevention in Rural Areas**

**Tom Seekins, PhD; Julie Clay, MPH; Judy Fredenberg, BA**

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*Sponsor: Center for Environmental Health and Injury Control, Centers for Disease Control*

**Purpose**—We are developing a replicable model for the surveillance and prevention of secondary disabilities in rural areas.

A secondary disability is any disability acquired after the diagnosis of a primary disability. For example, pressure sores are a secondary disability for a person with a spinal cord injury. Very little is known about secondary disabilities and much needs to be learned, including information concerning incidence, character, and severity.

**Progress**—Independent living (IL) philosophy suggests that one group to turn to for answers to these important issues are people with disabilities themselves. Consequently, we have surveyed and talked directly with over 200 consumers of IL centers in Montana to develop a Consumer-Directed Secondary Disability Surveillance Instrument.

**Results**—Eighty-nine consumers, with varying disabilities, rated the severity of 40 consumer-defined secondary disabilities on a scale of 0 (insignificant problem, rarely or never limits activity) to 3 (significant problem, limits activity 11 or more hours per week). We then calculated a Secondary Disability Problem Index by multiplying the percentage of respondents who indicated the condition was a problem by the average rating. By organizing the

results in this way, we are able to identify the most severe problems experienced by most respondents. Ten of the top 12 problems (mobility, access, fatigue, chronic pain, joint and muscle pain, physical conditioning problems, sleep disturbances, weight regulation, written communication problems, and depression) appear to have clear behavior or environmental (e.g., access) components.

**Implications**—If these findings hold across a larger number of respondents, they would suggest that health promotion and life-style management strategies, along with advocacy for access, might prove to be an effective approach to reducing the incidence and severity of secondary disabilities. Life-style intervention techniques could certainly be designed in a way compatible with both IL philosophy and rural service delivery.

These intervention techniques would involve encouraging individuals with disabilities to manage their own health care practices in ways that reduce their risk for secondary disabilities. Such interventions may be particularly useful in rural areas where access to knowledgeable professionals is limited.

#### **Publications Resulting from This Research**

None reported.



## [218] Technology Specialization (TechSpec) Program for Occupational Therapy

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**Sponsor:** *Office of Special Education Programs, Department of Education*

**Purpose**—Historically, formal training programs in assistive/rehabilitative technology have focused on in-service training via workshops, conferences, and on-the-job in-service sessions. In occupational therapy, exposure to assistive/rehabilitative technology in pre-service professional training curricula has been minimal to nil. It is becoming clear that pre-service training is imperative.

In recognition of this need, The Trace Center, in cooperation with the Occupational Therapy Professional Training Program at the University of Wisconsin-Madison, has established an interdisciplinary technology specialization program called TechSpec.

**Methodology**—The TechSpec program consists of two main components: direct training, and development and distribution of training materials. Direct training involves implementing a technology curriculum and training students at the University of Wisconsin-Madison. Training materials will be based on this curriculum and will be designed for those wishing to start similar programs elsewhere. Direct training is made available at two levels: foundation level and specialization level. Upon the successful completion of classroom and practicum instruction, TechSpec graduates qualify for a certificate in technology specialization.

**Progress**—Three new courses have been created for the TechSpec program, and two existing courses have been revised and incorporated into the program. In the fall semester of 1988-1989, 50 students enrolled in the initial course offering of the program. Eight are practicing Occupational Therapists (OTs), the rest are junior and senior OT students.

Two types of test have been administered: subjective self-tests and examinations. Both are administered for the whole program, not just for individual classes. Subjective self-tests measure students' perceptions of how much they know about technology—their "comfort level" with the topic. Examinations measure students' knowledge of the material. These are administered before and after students have been through the program.

**Results**—Results compiled from subjective and objective tests so far show strong increases in both comfort level and competency.

### **Publications Resulting from This Research**

**TechSpec: A Technology Training Model.** Smith RO, Christiaansen RA, Vanderheiden GC, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 327-328, 1989.

## [219] Wichita Rehabilitation Engineering Center: Development of a Mobile Rehabilitation Engineering Shop

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The Wichita Rehabilitation Engineering Center (REC) is a consortium of The Cerebral Palsy Research Foundation of Kansas (CPR) and The Wichita State University College of Engineering

(WSU). It is mandated by its funding agency, the National Institute on Disability and Rehabilitation Research (NIDRR), with the enhancement of the vocational opportunities of persons with severe

disabilities. CPR and WSU have a 17-year history of collaborative research that has resulted in the validation of the theory that severely disabled people can be productive in mainstream and supportive work environments through the utilization of rehabilitation technology.

During 1987-1988, Kansas Rehabilitation Services awarded CPR initial funding in the form of a Demonstration Grant for the development and operation of a Mobile Rehabilitation Engineering Shop which would provide rehabilitation technology services to remote areas of Kansas.

**Methodology**—REC staff had become increasingly aware of the problems encountered when rehabilitation engineering services were sought in rural, often remote, areas of the state. In the past, it had been necessary for engineers to make an initial visit to the site, analyze the situation, return to Wichita for device fabrication, and make a return trip for installation and training in its use. Therefore, delivery of services was subject to time delays that interfered with the client's ability to function independently.

It was believed that a mobile service delivery system would alleviate this problem by providing engineering services on-the-spot if the situation required a job-site modification at an existing industry or a tractor modification in the middle of a farmer's field. Services provided would include: 1) job-site modifications with the specific purpose of assisting the disabled to maximize their vocational skills; 2) manufacture of individualized equipment or devices to allow for greater independence in the home or community; 3) modification or repair of existing equipment; 4) dissemination of information and referral regarding equipment that can be purchased commercially; and, 5) consultation about job simplification techniques and home modifications.

**Results**—Upon receipt of the state grant funds in late September 1987, 5 months were spent in the

development of the unit. It consists of a 32-foot long "gooseneck" trailer coupled to a 1-ton crew cab pickup. Equipment includes: a lathe, mill, drill press, band saw, arbor press, three kinds of sanders/grinders, vises, portable table saw, air compressor, gas bottles and torches, a TIG welder, and a 12,500 watt diesel-powered electric generator to provide set-up at virtually any location.

Dedication of the unit was followed by a 3-month publicity tour during which all 31 state vocational rehabilitation offices were visited, presentations on Rehabilitation Engineering/mobile service delivery were made, and 29 clients received evaluation or consultation services.

The Mobile Shop has logged nearly 30,000 miles and has provided services to approximately 200 clients. Roughly 55 percent of the client contacts have resulted in the fabrication of assistive devices or modification of home or worksites. By the end of September 1989, the Mobile Shop concluded its third complete service delivery tour in addition to the publicity tour.

**Implications**—Proposals for continued grant support have been recently submitted and preliminary approval has been received. This grant proposes an expansion of facilities/personnel to include a minivan and another full-time engineer as well as 25-50 percent funding of a shop technician for fabrication support.

Our ultimate goal is to develop a fee-for-service system and wean the project off grant support after the next grant expires in September 1991. Currently, 7 states have contacted CPR seeking information on the Mobile Shop with the idea of developing a similar program in their area.

#### **Publications Resulting from This Research**

None reported.



## [220] New Models for Delivery of Personal Assistance Services

**Margaret A. Nosek, PhD; Marcus J. Fuhrer, PhD**

ILRU Research and Training Center on Independent Living, The Institute for Rehabilitation and Research, Houston, TX 77225

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Independence for hundreds of thousands of Americans is contingent upon availability of reliable sources of personal assistance. Personal assistance can enable even those with the most severe disabilities to have opportunities for self-direction and productivity in a setting of their own choice. Many people who need these services, however, do not receive them because of the lack of awareness of what personal assistance (also known as attendant services) is, unavailability of appropriate services, and most often, lack of funds to purchase needed services. While this issue is inestimable and critical to a substantial segment of the population, it has not been thoroughly subjected to scientific examination nor has it gained the attention of public policy makers.

To address this critical issue, the Independent Living Research Utilization (ILRU) Program was recently awarded a grant by the National Institute on Disability and Rehabilitation Research to examine personal assistance and its impact on the lives of people with severe disabilities. The project design involves a series of interrelated activities that include a comprehensive review and analysis of literature on personal assistance, development of criteria and indicators for assessing adequacy of personal assistance systems, evaluation of personal assistance programs using the adequacy criteria, a study of the role of personal assistance in health and employability of people with severe disabilities, a meeting to plan utilization of project findings, and an action agenda for personal assistance service needs nationally.

**Progress**—To date, *Personal Assistance for People with Disabilities: An Annotated Bibliography*, has been published which consists of summaries of over 150 publications related to personal assistance. Development of adequacy criteria and indicators continues. Early in the process, it was necessary to distinguish between assessment of adequacy from a consumer perspective versus a formal program review. Methodologies for administrative evaluation of programs are abundant and well-developed. In an effort to avoid “reinventing the wheel” and in deference to the need for consumer-focused adequacy criteria, development proceeded from a consumer perspective.

After an extensive review of literature, consultation with experts in the field, and site visits to consumers of two diverse personal assistance programs, a comprehensive list of criteria, with corresponding measurement items (indicators), critical to adequate personal assistance was generated. After further review for content validity by the panel of experts, adequacy criteria and measurement items will be refined as needed and tested for internal consistency and reliability.

Examination of the role of personal assistance in health and employability of people with severe disabilities is underway; open-ended interviews with a selected sample are being conducted in an effort to extricate the effects of personal assistance from other factors impacting on health and employability.

### **Publications Resulting from This Research**

None reported.

**[221] Independent Living in Rural Areas: A Longitudinal Study**

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ILRU Research and Training Center on Independent Living, The Institute for Rehabilitation and Research, Houston, TX 77005

*Sponsor: National Institute on Disability and Rehabilitation Research*

**Purpose**—Under a 3-year grant from the National Institute on Disability and Rehabilitation Research (NIDRR), Independent Living Research Utilization (ILRU) expanded independent living opportunities for disabled residents of rural areas. Six demonstration sites were established and given ongoing support until the project was completed in April 1986. The current Research and Training Center project is designed to examine the long-term effects of these interventions in terms of quality and quantity of ongoing activities and outcomes for the community.

**Progress**—The first component of this evaluation project has involved an initial assessment of two demonstration sites at the time that the ILRU rural demonstration grant was completed. This initial assessment allowed for the collection of baseline data to be used for comparison purposes following assessments in subsequent years. An 18-month follow-up assessment has been completed in two sites using the Community Needs and Resource Survey, as well as personal interviews with people with disabilities, religious leaders, and media representatives. Crockett, TX, and Kerrville, TX, were chosen for the in-depth studies. Results reflect the different needs that are predominant in each community.

**Results**—The independent living project in Crockett resulted in establishment of a fully operational center for independent living. The Kerrville project, while having a positive impact on a number of accessible public buildings and the number of citations for illegal parking in handicapped spaces, did not lead to the development of a Center for Independent Living (CIL). From 1984 to 1988, a substantial increase in accessibility in the following areas was realized in Crockett: health care, housing, employment, attendant care, information and referral services, and public buildings. Personal interviews substantiated data collected by the Community Needs and Resource Survey. Information gathered brought to light the importance of several factors in the successful establishment of CILs in rural communities: real and perceived needs of persons with disabilities in the community, availability and adequacy of existing resources to meet needs, and the availability of people to provide leadership and continuing efforts. Currently, an article describing the study is being prepared.

**Publications Resulting from This Research**

None reported.

**[222] Parameters of Independent Living Programs: A Longitudinal Study**

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*Sponsor: National Institute on Disability and Rehabilitation Research*

**Purpose**—The purpose of this project is to maintain a database on the status of independent living programs nationally, and to identify trends in the development of independent living programs, the emergence of issues encountered in the delivery of independent living services, and changes in the characteristics of consumers of these services.

**Progress**—Profiles of each program responding to a full-length survey have been published in the Independent Living Research Utilization (ILRU) Registry of Independent Living Centers (ILCs). In late 1988, a revised and updated survey instrument was mailed to over 400 programs listed in the ILRU Directory of Independent Living Programs. Infor-



mation was solicited concerning populations served, services provided, characteristics of persons providing services, methods by which services are provided and programs administered, sources of funding, and relationships between programs and their communities. Approximately 50 percent of the programs have responded; currently, a shortened version of the survey is being sent to nonrespondents.

**Results**—Analysis of the 1986 administration of the survey has yielded interesting information. An examination of program compliance with key requirements of Title VII, the independent living provision of the 1978 Rehabilitation Act, resulted in a finding of low compliance levels. Only 51 percent of programs receiving Title VII funds met requirements for consumer involvement in program direction and management, and service delivery. There was no relationship between compliance and receipt of Title VII funds or amount of Title VII funds received. Complying programs offered significantly more services and served significantly more persons than noncomplying programs. These findings have strong implications for federal policy and funding in the area of independent living.

Additional analysis was done to determine the impact of age of program, consumer control, and

budget size on the operation of independent living programs. Results reflected the wide diversity of program characteristics. Older programs tended to have more diverse funding. Programs with higher levels of consumer control tended to have more staff with disabilities, engaged in more advocacy activities, and participated more in networks. Programs with larger budgets were more likely to offer residential housing services and were less active in advocacy and awareness activities. Longitudinal analysis is planned for comparison of the 1984, 1986, and 1988 studies.

**Future Plans**—The *Directory of Independent Living Programs* is updated and reissued approximately five times per year. Research staff will continue to update it and respond to specific inquiries with individualized data runs and reports. Analysis will continue on the ILRU National Database on Independent Living Programs.

#### Publications Resulting from This Research

**Levels of Compliance with Federal Requirements in Independent Living Centers.** Nosek MA, Jones SD, Zhu Y, *J Rehabil* 55(2):31-37, 1989.

**Independent Living Programs: The Impact of Program Age, Consumer Control, and Budget on Program Operation.** Nosek MA, Roth PL, Zhu Y, *J Rehabil* (accepted for publication).

## [223] High School Pre-Vocational Intervention Study

**David C. Clemmons**

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**Sponsor:** National Institute of Neurological Disorders and Stroke, National Institutes of Health

**Purpose**—A pre-vocational intervention is proposed which is designed to assist epilepsy-impaired high school seniors to enter competitive employment at an early time. It is hypothesized that the treatment group, relative to placebo and no-treatment controls, will demonstrate: 1) a higher rate of entry into competitive employment; and, 2) a reduced rate of dependence on public subsidy. The treatment is presented in a group format, designed after successful group formats currently used in this center for adult outpatients with epilepsy.

The vocational difficulties of persons with epilepsy include elevated rates of unemployment and

historically low rates of movement into competitive employment through state rehabilitation agencies. Much of the current literature suggests that job development strategies, and not traditional skills-training programs, are most effective in assisting brain-impaired persons to secure competitive jobs. Initiating vocational habilitation work at the high school level is believed to be desirable because: 1) individuals with early onset of epilepsy are more likely to exhibit deficits in neuropsychological, intellectual, and social status than are individuals with post-adolescent onset; 2) chronic unemployment as a life style may occur early in this

population; and, 3) there may be locus of control, or learned helplessness factors present which are more amenable to early intervention.

**Progress**—Pilot work is presented which suggests the feasibility of using neuropsychological testing results obtained from high-school-age epileptics as an index of later vocational status. Pilot work also shows an early reliance on public subsidy for epileptics who were subjects in a post-high school vocational status study.

Hypothesis testing will proceed by means of *t*-tests, rank correlation coefficients, and distribution-free analyses of variance, and will be adjusted for multiple comparisons. Multiple rank regression methods will be used as an aid in identifying types of individuals who may be expected to benefit from extended or specialized services.

**Publications Resulting from This Research**

None reported.



# VII. Functional Electrical Stimulation

*For additional information on topics related to this category see the following Progress Reports: [44], [46], [51], [330], [333], [334], [335], [347], [350].*

## A. General

### [224] Simulation of Functional Electrical Stimulation of a Nerve Trunk

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**Robert Plonsey, PhD**

Department of Biomedical Engineering, Duke University, Durham, NC 27706

Sponsor: *National Science Foundation*

**Purpose**—The goal of this research is to develop and examine models that permit the evaluation of excitation of fibers within a nerve trunk to an extracellular point source stimulus. A requirement of the model is that it take into account the specific stimulating field at different locations within the bundle. This requires that the bundle geometry, fiber geometry, and the electrical properties of fibers and medium be taken into account.

**Methodology/Results**—Results were obtained by solving for the applied field using a biodomain model representation for the bundle as a whole. Then the response of a specific fiber was evaluated by considering it to lie in the resulting field. Only the steady-state subthreshold response was examined, though this should provide a good indication

of the relative response to a given stimulus as a function of location within the bundle.

In the course of the work, an investigation was conducted on the “activating function” of Rattay, and on the possible alternate formulations that would be more satisfactory. In addition, an examination of the validity of present measured intracellular and interstitial conductivities was undertaken.

#### **Publications Resulting from This Research**

**Development of a Model for Point Source Electrical Fibre Bundle Stimulation.** Altman KW, Plonsey R, *Med Biol Eng Comput* 26:466-475, 1988.

**Electrical Stimulation of Excitable Cells: A Model Approach.** Plonsey R, Altman KW, *Proc IEEE* 76:1122-1129, 1988.

**Analysis of the Longitudinal and Radial Resistivity Measurements of the Nerve Trunk.** Altman KW, Plonsey R, *Ann Biomed Eng* 17:313-324, 1989.

### [225] Electrical Stimulation of Osteogenesis Using Selected Techniques

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Emory University School of Medicine, Atlanta, GA 30303

Sponsor: *VA Rehabilitation Research and Development Service (Project #A331-RA)*

**Purpose**—This project involves the use of various selected electrical stimulation techniques for growth

and repair of bone. The overall goal is to determine an effective technique to be employed in research

planned to evaluate the appropriateness of electrical stimulation therapy to remobilize patients with loose prosthetic devices (trauma and irritation present) and patients with osteopenia (trauma and irritation absent). The specific aims are to: 1) define a dose response relationship in magnetic field amplitude for electromagnetic stimulation (EMS) produced by a sinusoidal waveform; 2) determine whether trauma and irritation are required with EMS produced by either a sinusoidal or a square-pulse waveform; and, 3) compare the efficacy of direct current stimulation (DCS), EMS by sinusoidal waveform, and EMS by a square-pulse waveform in the same animal model.

**Methodology**—Throughout this project, the tissue site selected for electrical treatment is the rabbit tibial medullary canal. Surgical intramedullary insertion and implantation of a flexible, nonmetallic rod is used to produce trauma and irritation in intact tibia where indicated by experimental design. Such trauma and irritation may be required to elicit cells responsive to electrical stimulation treatment. The biological response within the medullary canal after electrical treatment is evaluated by histomorphometric quantitation of new bone formation, necrotic tissue, and selected cell types.

Originally, restraint and anesthesia of the animals, used previously by others in similar experiments, were to be employed in this research to permit daily placement of electrical devices and appliances, as well as the stimulation treatment. However, excessive restraint, prolonged anesthesia, and consequent inactivity of the animals usually results in loss of weight, health, and, not infrequently, life. To avoid these complications, a system consisting of a jacket, tether, and swivel was developed to permit routine electrical stimulation

treatment of animals with devices and appliances from any stimulation technique. It was believed that such a system would help establish a more accurate index of the biological response to electrical stimulation with *in vivo* models. The jacket-tether-swivel system allows the animal to have freedom of movement within its cage with access to both food and water *ad libitum*.

A group of 12 animals completed treatment with electromagnetic stimulation by a sinusoidal waveform of three different amplitudes using the above system. The group sustained the treatment without restraint or anesthesia and there was no loss of weight, health, or life.

**Preliminary Results**—As a result of contact with edges of external electrical appliances, skin irritation was observed in several cases. Traumatic periosteal bone formation in these regions was not found. To date, intramedullary bone formation has not been indicated radiographically or histologically in any animal that sustained electromagnetic stimulation by sinusoidal waveform regardless of stimulus amplitude at the frequency tested.

**Future Plans**—The coil pair, an appliance required with electromagnetic stimulation, was completely redesigned to reduce its overall size and thus reduce skin irritation. Additional wire turns in each coil, mounted on a lightweight support, have also been incorporated. These new coil pairs, powered by a new circuit designed to deliver higher frequency EMS by square-pulse waveform, will be employed in subsequent experiments of this research project.

#### **Publications Resulting from This Research**

None Reported.

### **[226] Intramuscular Diaphragm Stimulation for Ventilatory Assist**

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Sponsor: VA Rehabilitation Research and Development Service (Project #B186-2RA)

**Purpose**—The purpose of this study is to complete the pre-clinical studies of chronic electrical stimulation for ventilatory assist through direct activation

of the diaphragm muscle. In the past, ventilatory pacemakers have included stimulation of the thorax, central nervous system, and peripheral nervous



system. Our animal research over the past 5 years has demonstrated that activation of the phrenic nerve through placement of electrodes directly into the diaphragm muscle can eliminate many of the risks of traditional phrenic nerve pacers and provide a more extensive clinical use for electrically induced ventilation.

**Methodology**—We expect the first clinical trials of this method to be performed with populations of chronic central hypoventilators and nonparalyzed ventilator-dependent patients. The device that will be used to activate the diaphragm muscle is the same percutaneous, multichannel, neuromuscular stimulator that was developed at the Applied Neural Control Laboratory, at Case Western Reserve University, for scoliosis studies.

Intramuscular electrodes will be implanted into the diaphragm using a procedure in which the abdomen is insufflated and a laparoscope is placed through the abdominal wall using a trochar tube.

**Progress**—Progress includes completion of animal studies, design and testing of the electrode, diaphragm mapping, and meeting the regulatory requirements.

*Completion of animal studies.* Animal studies have shown that intramuscular activation of the unconditioned diaphragm muscle provides at least 120 percent of the minute volume required for basal metabolic needs in the absence of ventilation in dogs. Following 4 to 6 months of full-time, bilateral, intramuscular stimulation, more than 200 percent of the required tidal volume was produced.

*Design and testing of electrode.* A new electrode design was developed for intramuscular stimulation. The new electrode has a polypropylene core running the length of the coil, and a cluster of polypropylene barbs at the electrode tip. Prelimi-

nary studies have shown a 4- to 6-fold increase in the pulling force required to dislodge the electrode tip from its position. Tissue studies have shown that the new electrode elicits no detrimental tissue response.

*Diaphragm mapping.* Efficient activation of the phrenic nerve using an electrode placed in the diaphragm muscle is critically dependent on electrode placement. Our method of placement uses an abdominal laparoscopic procedure. This procedure, as well as the human anatomy itself, presents a unique set of problems. The electrode must be placed close enough to the phrenic nerve entry point into the muscle to activate the nerve using a safe stimulus pulse; however, the entry point is not visible from the abdominal side of the diaphragm. We are conducting experiments to determine the location for optimal electrode placement for diaphragm stimulation. The experiment will indicate necessary procedural changes and expedite the implementation of clinical intramuscular diaphragm stimulation.

*Fulfillment of regulatory requirements.* We are in the process of preparing the documentation for institutional review board (IRB) approval and for an investigational device exemption (IDE) from the FDA.

**Future Plans**—In the next year, we plan to complete the surgical mapping studies and begin to implement the diaphragm stimulation system in a clinical setting.

#### Publications Resulting from This Research

**Electrical Activation of the Diaphragm.** Nochomovitz ML, Peterson DK, Stellato TA, *Clin Chest Med* 9(2):349-358, 1988.

**Electrical Activation of Respiratory Muscles by Methods Other Than Phrenic Nerve Cuff Electrodes.** Peterson DK, et al., *PACE*, 2:854-860, 1989.



## [227] Evaluation of FES Techniques for Exercise

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Sponsor: VA Rehabilitation Research and Development Service (Project #B433-RA)

**Purpose**—The purpose of this project is to objectively evaluate the effectiveness of functional electrical stimulation (FES) exercise techniques for improving health, physical fitness, and rehabilitation potential of patients with spinal cord injury (SCI). Specific objectives include: 1) assessment of acute physiologic responses and maximal performance during FES leg cycling (FES-LC) exercise, FES knee extension (FES-KE) exercise, voluntary arm-crank exercise (ACE), and combined FES-LC + ACE (HYBRID) exercise; and, 2) determination of physiologic and psychologic adaptations resulting from training with the various FES/voluntary exercise modes.

**Progress**—Upon completion of Year One of this 4-year project, a sophisticated FES-KE exercise system and a fully adjustable arm-crank ergometer mounting stand were designed, and 5 of these devices were constructed. To date, 40 SCI subjects are involved in the research, of which 17 have completed at least one of the four 12-week training programs involving FES-induced exercise.

**Preliminary Results**—Mean passive range of knee motion and quadriceps muscle strength and endurance significantly increased for both the FES-KE and FES-LC training groups. Compared with able-bodied (AB) subjects performing voluntary leg cycling, SCI subjects performing FES-LC at equal power outputs (POs) displayed higher levels of oxygen uptake ( $\dot{V}O_2$ ), heart rate (HR), and pulmonary ventilation ( $\dot{V}_E$ ). Calculated gross, net, work, and delta efficiencies for SCI subjects were approximately one-half of those for AB subjects at all POs. FES-LC elicited marked metabolic and central hemodynamic responses in untrained SCI subjects, with  $\dot{V}O_2$  and cardiac output ( $\dot{Q}$ ) increasing 3.5 and

2.5 times above resting levels, respectively. Compared with quadriplegics, paraplegics displayed significantly higher mean peak  $\dot{Q}$ , stroke volume (SV), and blood pressure (BP). In addition, FES-LC for quadriplegics elicited higher peak levels of  $\dot{Q}$ , SV, and BP, at lower levels of peak PO, HR, and  $\dot{V}_E$  than for ACE, suggesting that FES-LC may be a more effective means for central cardiovascular training. In comparison to ACE, markedly high blood lactate levels have been observed at all POs during FES-LC.

HYBRID exercise testing resulted in significantly higher levels of all cardiopulmonary responses except SV, suggesting greater training capability with this combination exercise than either FES-LC or ACE performed alone. Proximal tibial bone density measurements are being conducted using a quantitative computerized tomography (CT) scanner to determine if FES exercise can influence the existing osteoporosis.

**Future Plans/Implications**—Findings suggest that FES-LC is mechanically inefficient, which may be advantageous due to the greater magnitudes of metabolic and cardiopulmonary responses that can be elicited at relatively light mechanical loads. An additional phase of training has been added to evaluate the efficacy of interval training (versus continuous training) for SCI cardiopulmonary fitness improvement. A computerized system to assess the interrelationships of muscle force production, FES current, and electromyographic activity is currently under evaluation. This device can objectively document stimulation threshold, maximal force output, and the rate of muscle fatigue before and after experimental treatments. Psychological test results are being evaluated to identify correlates with subject attrition and fitness improvements.



### Publications Resulting from This Research

- Automated Autonomic Nervous System Function Analysis System.** Ezenwa BN, Figoni SF, Glaser RM, et al., in *Proceedings of the 10th Annual Conference IEEE/EMBS*, 1210-1211, 1988.
- Central and Peripheral Etiology of Fatigue for the Disabled.** Glaser RM, *Didactic Program, American Association of Electromyography and Electrodiagnosis*, 21-26, 1988.
- Hemodynamic Responses of Quadriplegics to Maximal Arm-Cranking and FNS Leg Cycling Exercise.** Figoni SF, Glaser RM, Hendershot DM, et al., in *Proceedings of the 11th Annual Conference IEEE/EMBS*, 1636-1637, 1988.
- Physiologic Responses of SCI Subjects to Electrically Induced Leg Cycle Ergometry.** Glaser RM, Figoni SF, Collins SR, et al., in *Proceedings of the 10th Annual Conference of IEEE/EMBS*, 1638-1639, 1988.
- Force-Current Measurement System for Evaluating Muscle Performance During Functional Neuromuscular Stimulation.** Ezenwa BN, Glaser RM, Almeyda J, et al., in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 179-180, 1989.
- Hemodynamic Responses of Paraplegics and Quadriplegics to Passive and Active Leg Cycle Ergometry.** Figoni SF, Glaser RM, Rodgers MM, et al., *Am Spinal Injury Abst Digest*, 80, 1989.
- Hemodynamic Responses of Quadriplegics to Arm, ES-Leg, and Combined Arm + ES-Leg Ergometry.** Figoni SF, Glaser RM, Rodgers MM, et al., *Med Sci Sports Exerc* 21(2) (Suppl):S96, 1989.
- Peak Hemodynamic Responses of SCI Subjects During FNS Leg Cycle Ergometry.** Figoni SF, Glaser RM, Hooker SP, et al., in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 97-98, 1989.
- Physiologic Responses to Simultaneous Voluntary Arm Crank and Electrically-Stimulated Leg Exercise in Quadriplegics.** Hooker SP, Glaser RM, Figoni SF, et al., in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 99-100, 1989.
- Tibial Trabecular Bone Density vs Time Since Spinal Cord Injury.** Rodgers MM, Hangartner TN, Barre PS, et al., in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 403-404, 1989.
- Wheelchair Dependent Individuals.** Glaser RM, Davis GM, in *Exercise in Modern Medicine*, 237-267, B.A. Franklin, S. Gordon, G.C. Timmis (Eds.), Baltimore: Williams & Wilkins Co., 1989.
- Arm Exercise Training for Wheelchair Users.** Glaser RM, *Med Sci Sports Exerc* (in press).
- Efficiency of FNS Leg Cycle Ergometry.** Glaser RM, Figoni SF, Hooker SP, et al., in *Proceedings of the 11th Annual Conference IEEE/EMBS* (in press).
- Exercise Conditioning of the Spinal Cord Injured Via Functional Electrical Stimulation.** Glaser RM, in *Athletic Injuries to the Head, Neck and Face*, 2nd ed., J.S. Torg (Ed.), Chicago: Yearbook Medical Publishers (in press).
- Feasibility of Using Two FNS Exercise Modes for Spinal Cord Injured Patients.** Faghri PD, Glaser RM, Figoni SF, et al., *Clin Kinesiol* (in press).
- Fitness Following Spinal Cord Injury.** Davis GM, Glaser RM, in *Physiotherapy: Foundations for Practice Series, Neurology Volume*. L. Ada, C. Canning (Eds.), London: Heinemann Medical Books (in press).
- Functional Neuromuscular Stimulation for Physical Fitness Training of the Disabled.** Glaser RM, in *Fitness for Aged, Disabled and Industrial Workers*, M. Kaneko (Ed.), Champaign, IL: Human Kinetics Publishers (in press).
- Spinal Cord Injuries and Neuromuscular Stimulation.** Glaser RM, in *Current Therapy in Sports Medicine*, Chapter 2, J.S. Torg (Ed.), Toronto: B.C. Decker, Inc. (in press).

### [228] FNS-Effects Upon Venous Pooling in Geriatric and Mobility-Impaired Patients

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Sponsor: VA Rehabilitation Research and Development Service (Project #B242-3RA)

**Purpose**—The overall purpose of this research program is to evaluate the acute effects of pulsatile functional neuromuscular stimulation (FNS)-induced contractions of leg muscles upon central and peripheral hemodynamic responses to determine if venous pooling/stasis can be minimized and/or reversed in mobility-impaired and geriatric patients. Specific objectives are to evaluate the effectiveness of this FNS application for facilitating circulation during head-up tilt, lower body negative pressure,

upright sitting, standing, arm-crank exercise, and wheelchair propulsion.

**Progress**—Twenty-five hemiplegic and other disabled geriatric subjects are engaged in preliminary medical, orthostatic, exercise, and FNS tolerance tests. Instrumentation that has been designed and constructed for implementing this research program includes: 1) 8-channel neuromuscular stimulators, utilizing a less painful low-current electrical



waveform, to alternately contract thigh and calf musculature; 2) a motorized tilt table with adjustable arm-crank ergometer to allow arm-crank exercise during tilting; 3) two lower-limb negative pressure chambers to experimentally induce venous pooling; 4) an 8-segment impedance cardiographic/arteriographic data collection and analysis system to monitor central and peripheral circulation; and, 5) a system that measures bioelectrical resistance, reactance, and impedance in 8 segments of the body simultaneously for assessment of segmental fluid shifts and fluid volumes. Both impedance systems will be used to assess physiologic responses during postural change, arm exercise, and effectiveness of FNS-activation of the skeletal muscle pump for minimizing venous pooling and enhancing venous return.

**Future Plans/Implications**—If this FNS application can reduce venous pooling in the legs and improve circulation to exercising arm muscles, it may be able to enhance arm exercise capacity, decrease the stressfulness of manual wheelchair locomotion, and improve the tolerance for upright postures for prolonged durations. Future medical and rehabilitative applications may also include prevention of deep venous thrombosis in immobilized or post-

surgical patients and treatment of orthostatic hypotension, excessive pedal edema, and decubitus ulcers in susceptible individuals.

#### Publications Resulting from This Research

**Central Hemodynamic Responses to Lower-Limb FNS.** Glaser RM, Rattan SN, Davis GM, et al., in *Proceedings of the 9th Annual IEEE/EMBS Conference*, 615-617, 1987.

**Cardiovascular Responses to Exercise in Young and Middle-Aged SCI Subjects.** Rodgers MM, Figoni SF, Glaser RM, et al., in *Proceedings, ICAART 88*, Montreal, 160-161, 1988.

**Cardiovascular Responses to FNS-Induced Isometric Leg Exercise During Orthostatic Stress in Paraplegics.** Davis GM, Figoni SF, Glaser RM, et al., in *Proceedings, ICAART 88*, Montreal, 326-327, 1988.

**FNS-Assisted Venous Return in Exercising SCI Men.** Figoni SF, Davis GM, Glaser RM, et al., in *Proceedings, ICAART 88*, Montreal, 328-329, 1988.

**FNS-Enhancement of Central Hemodynamic Performance in Paraplegics During Tilting.** Figoni SF, Davis GM, Glaser RM, et al., in *Am Spinal Injury Abs Digest*, 153, 1988.

**A Multichannel Stimulator for FNS Applications.** Glaser RM, Collins SR, in *Proceedings, ICAART 88*, Montreal, 344-345, 1988.

**Semi-Automated Analysis System for Impedance Cardiography.** Ezenwa BN, Figoni SF, Glaser RM, et al., in *Proceedings of the 2nd Annual Dayton VAMC Research Seminar*, 29, 1988.

**Cardiovascular Responses to FNS-Induced Isometric Leg Exercise During Lower Body Negative Pressure.** Davis GM, Williamson JW, Pawelczyk JA, et al., in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 95-96, 1989.

#### [229] Development of a High Performance Multichannel Surface Electrical Stimulation System

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**Sponsor:** NATO; Ministry of Education of Italy; Biomedical Engineering Center, Ohio State University

**Purpose**—A multichannel computer-controlled stimulation system is being developed for testing functional electrical stimulation (FES) parameters and strategies. Applications are in the field of external control of paralyzed human extremities and neuromuscular physiology. The system is based on an IBM/AT computer, it provides up to 8 channels of output, and it is suitable for closed-loop operation. The system may be used to program a portable stimulation unit. The first year of a 2-year project has been completed.

**Results**—Particular attention has been devoted to the outline of a design that would allow maximal versatility as well as future development and expansion. The system consists of three main blocks: 1) the computer; 2) a microprocessor-based sub-system that receives data from the computer and generates the stimulation pulse trains; and, 3) a set of output stages.

The computer is used mainly as a friendly-user interface to provide housekeeping, graphic output, and easy programming of the sub-system. Stimula-



tion waveforms and their envelopes are selected from a library or defined via a mouse. Stimulation parameters are then transferred to the sub-system via a IEEE 488 link and may be updated at any time. The sub-system generates the specified pulses in analog form and applies them to the output stages. The computer may change any parameter before stimulation begins, and can change the stimulus amplitude, duration, and repetition rate during the stimulation. Modulation of amplitude and duration of the stimulus waveform is possible for individual channels, while stimulation rate modulation is possible for sets of 4 channels. The output

stages are isolated, may operate in either the constant voltage or constant current output mode or in a "hybrid" mode (current output during stimuli and voltage output between stimuli) to reduce the stimulation artifact and allow detection and processing of the elicited M-wave.

Design and construction of the sub-system and of the output stages have been completed and testing is under way. The open loop version of the system will be completed in the second year.

#### **Publications Resulting from This Research**

None reported.

### **[230] Treatment and Prevention of Secondary Complications of Spinal Cord Injury**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The purpose of the grant is to study a number of complications of spinal cord injury and methods for their prevention. Our studies include: 1) application of functional electrical stimulation (FES) to promote standing in paraplegic adult human subjects; 2) applications of FES to assist upper limb motilization in quadriplegic subjects; 3) acceptability of FES as a therapeutic option in paraplegic human subjects; 4) substance abuse and dependance in spinal cord injured subjects; 5) prevention of thromboembolic complications in subjects with spinal cord injury, using a low molecular weight heparin; 6) expiratory muscle training as a means to augment ventilatory performance; 7) use of vibratory stimulation to augment fertility or to prevent infertility in spinal cord injured males; 8) techniques for the prevention of urinary tract infection; and, 9) use of computer-assisted devices to improve skin care in subjects with the potential for pressure sores.

**Methodology**—Methodologies range from statistical evaluation of patient records to patient and family questionnaires, to direct experimental testing using electrical stimulation of quadriceps and other mus-

cles of the limb. Bacteriological techniques are used for the study of urinary tract infection and hematological techniques for the study of blood clotting.

#### **Publications Resulting from This Research**

**Functional Electrical Stimulation Enhances Fibrinolytic Activity in Spinal Cord Injury Patients.** Katz RT, Green D, Sullivan T, Yarkony G, *Arch Phys Med Rehabil* 68:423-426, 1987.

**Functional Outcome Following Spinal Cord Injury: A Comparison of Specialized Spinal Cord Injury Center Versus General Hospital Acute Care.** Heinemann AW, Yarkony GM, Roth E, Lovell L, Hamilton B, Meyer PR, Brown JT, *Paraplegia* 26:114-115, 1988.

**Functional Skills After Spinal Cord Injury Rehabilitation: Three-year Longitudinal Follow-up.** Yarkony G, Roth E, Heinemann A, Lovell L, Wu Y, *Arch Phys Med Rehabil* 69:111-114, 1988.

**Rehabilitation Outcomes in C5 Quadriplegia.** Yarkony G, Roth E, Heinemann A, Lovell L, *Am J Phys Med Rehabil* 73, 1988.

**Rehabilitation Outcomes in Complete C5 Quadriplegia.** Yarkony G, Roth E, Lovell L, Heinemann A, Katz RT, Wu Y, *Am J Phys Med Rehabil* 67:73-76, 1988.

**Rehabilitation Outcomes in C6 Tetraplegia.** Yarkony G, Roth E, Heinemann A, Lovell L, *Paraplegia* 26:177-185, 1988.

**Spinal Cord Injury Rehabilitation Outcome: The Impact of Age.** Yarkony G, Roth E, Heinemann A, Lovell L, *J Clin Epidemiol* 41:173-177, 1988.



### [231] FES-Aided Paraplegic Gait Using a Controlled-Brake Orthosis

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**Sponsor:** *Biomedical Research Support Grant, National Institutes of Health*

**Purpose**—Restoration of gait to paraplegics using functional electrical stimulation (FES) is a challenging problem. A crucial difficulty is controlling the FES system for stability and smooth gait. One option for improving control is to develop implanted systems with large numbers of stimulation channels and complex control algorithms. However, simple surface stimulation programs should continue to be explored because they involve no surgery. One means of improving walking function using surface stimulation is to add a mechanical orthosis in combination with FES.

Based on the preliminary work of our group, we are proposing to address the problem of designing a functional FES-aided gait system using surface stimulation by investigating a new device which may improve the quality of gait. The device incorporates a knee orthosis containing a controllable friction brake at the joint. The purpose of the brake is to shift the burden of control in a gait trajectory from controlling the stimulated muscles and spastic reflexes to controlling the brake, a well-behaved mechanical element. The controllable brake also provides a means of locking the knee joint during periods of quiet standing, which may reduce overall muscle fatigue. Further, the brake can provide a rigid brace mode, which may be safer in the event of a stimulation failure.

To evaluate brake designs and performance, we will quantitatively test and compare the ability of

SCI paraplegics to achieve FES-aided gait both with and without the brace. The assessment will include kinematic, dynamic, and metabolic variables.

**Progress**—Pilot studies based on stimulation of able-bodied subjects to control the knee joint demonstrated the utility of the controlled-brake approach. By combining fine control of the brake with gross control of muscle stimulation, performance on position tracking tasks was greatly improved over both open and closed-loop control schemes, which used stimulation alone.

**Future Plans**—We are building a computer-controlled, 8-channel stimulator and a preliminary version of a controlled-brake orthosis for the knee joint. We are also embarking on a training program of FES-aided lower limb exercise and standing to generate a pool of suitable subjects for our gait studies. We plan to make use of a related study on monitoring EMG as a muscle state indicator during electrical stimulation. The clinical studies will be conducted at the West Roxbury VA Medical Center.

#### **Publications Resulting from This Research**

**Braked Hybrid FES-Orthosis for Restoring Paraplegic Gait: Concept and Single-Joint Emulator.** Durfee W, in *Computation Methods in Bioengineering*, R.L. Spilker, B.R. Simon (Eds.), 473-479, 1988.

### [232] Noninvasive Stimulation of Human Central Nervous System

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—Our purpose is to investigate the noninvasive stimulation of the human central nervous system (CNS).

Recently, techniques have become available for the noninvasive stimulation of the human cortex and

human spinal cord. A device has been manufactured which produces a high voltage, extremely brief pulse which can penetrate the skull and activate the CNS without excessive pain. Previous studies have shown it useful in some circumstances where evaluation of



the speed and integrity of motor pathways is valuable.

**Preliminary Results**—We have succeeded in mapping the hand, arm, leg, and mouth areas of the human motor cortex in normal volunteers and correlating these motor maps with the sensory maps as defined by using somatosensory-evoked potentials. At this time we are studying changes in these sensorimotor maps in patients with mirror movements, stroke, and with different types of amputations.

We have found that patients with congenital mirror movements have a bilateral cortical representation of each hand in the motor cortex, and also,

that they have physiologically active and fast conducting connectors between the motor cortex and ipsilateral muscles in the upper extremity. We have also found that EEGs do not change after a session of cortical stimulation in normal volunteers, which indicates the safety of the procedure. We have established normative data for our own laboratory for measurement of motor conduction velocities using electrical stimulation. We have started to use magnetic stimulation and are trying to develop a technique capable of delivering focal painless transcranial stimuli.

#### **Publications Resulting from This Research**

None reported.

### **[233] Continuous Monitoring of Time-Varying Evoked Potentials**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—Our purpose was to develop a new technique to monitor transient and time-varying evoked potential signals.

**Progress/Methodology**—Our idea was to construct a Fourier series model of the evoked potential signal and employ an adaptive filtering algorithm that minimizes the mean-squared error between the signal ensembles and the model. The adaptive algorithm allows us to track time-varying changes in the signal, while the Fourier series model allows us to track complex changes in morphology. The theoretical analysis shows how to select optimal convergence parameter values and model order for the signal. A trade-off exists between the convergence parameter and the mean-squared error of the estimate, and a formula has been developed to relate the two. The simulation results show rapid convergence of this algorithm and ability to follow transient changes in amplitude, latency, and morphology.

**Results**—Two experimental protocols have been completed to validate the technique: somatosensory evoked potentials from anesthetized cats during

hypoxic hypoxia, and response to etomidate anesthetic in human subjects. In response to hypoxic hypoxia, we observed an unusual dispersion in the spectral content of the signal that was not apparent from simply tracking time-varying changes in signal amplitude and latency. It appears that the spectral content of the signal may provide added diagnostic information. In response to etomidate gas, we observed transient elevation in the signal amplitude. This rapid response was captured by our technique.

**Future Plans/Implications**—These studies suggest that our technique may be suitable for evoked potential data analysis where rapid or transient signals are encountered and there is a complex alteration in signal morphology. This work has application to patient monitoring in, for example, neurological critical care and surgery. New clinically-applicable protocols are currently being investigated.

#### **Publications Resulting from This Research**

**Adaptive Fourier Estimation of Time-Varying Evoked Potentials.** Vaz CA, Thakor NV, *IEEE Trans Biomed Eng* 36:448-455, 1989.



### [234] Control of Limb Joint with Electrical Stimulation of Agonist-Antagonist Muscles

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**Sponsor:** *National Science Foundation*

**Purpose**—Electrical stimulation of an agonist muscle alone yields, at best, poor control of force and position of its associated joint in non-isometric, free motion. Physiologically, co-activation of agonist-antagonist muscles is known to provide control and stability of joint motion. Several attempts by other groups to apply functional electrical stimulation (FES) to agonist-antagonist muscles were performed on a trial-and-error basis and yielded poor results, being oblivious to the basic information on physiological co-activation patterns.

We have undertaken to investigate the patterns of muscular co-activation of several major limb joints under diverse motion conditions with the objectives of utilizing the data as specifications for application of FES to control a limb joint.

**Progress**—It was found that while the agonist muscle is concerned with the primary mission of performing the intended task, the antagonist assumes regulatory functions, compensating for a wide range of external and internal disturbances.

Some of the most prominent disturbances compensated by the antagonist muscles are: orientation of the moving limb mass with respect to gravity, joint angle, muscle moment arm, limb velocity, acquired skill of motion performance, previous exercise history, joint stability, and its anatomical integrity under load.

#### Publications Resulting from This Research

**The Synergistic Action of the ACL and Thigh Muscles in Maintaining Joint Stability.** Solomonow M, Baratta R, Zhou B, Shoji H, Beck C, Bose W, D'Ambrosia R, *Am J Sports Med* 15:207-218, 1987.

**Muscular Co-Activation: The Role of the Antagonist Musculature in Maintaining Joint Stability.** Baratta R, Solomonow M, Zhou B, Letson D, Chuinard R, D'Ambrosia R, *Am J Sports Med* 16:113-122, 1988.

**EMG Co-activation Patterns of the Elbow Antagonist Muscles During Slow Isokinetic Motion.** Solomonow M, Baratta R, Zhou B, D'Ambrosia R, *Exp Neurol* 100:470-477, 1988.

**The Impact of Joint Velocity on the Contribution of the Antagonist Musculature to Knee Stiffness and Laxity.** Hagood S, Solomonow M, Baratta R, Zhou B, D'Ambrosia R, *Am J Sports Med* (in press).

### [235] EMG Power Spectra Frequencies Associated with Various Motor Unit Recruitment Strategies of Skeletal Muscles

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**Purpose**—As skeletal muscles increase their contractile force, motor units of progressively larger size are recruited into activity. As the size of the motor unit increases, so does the conduction velocity of action potentials propagating in its nerve axon and muscle fibers. It is well known that the median frequency (MF) of the electromyogram (EMG) power spectrum density is directly proportional to the MF. One can therefore hypothesize that as long as motor units are

recruited in an increasing force contraction, the average conduction velocity of action potentials increases, and so will the EMG's MF. Applications of such findings, if verified, have a wide range of uses in motor control, muscle and EMG research, as well as in the use of EMG as feedback in functional electrical stimulation (FES) systems.

With the use of our newly-developed stimulation method which can allow orderly recruitment of



motor units with simultaneous, but independent, control of firing rate, and at various control strategies, we investigated the hypothesis set above.

**Progress**—It was found that the EMG's MF increases nearly linearly as motor units are orderly recruited. Variations of the firing rate did not affect the MF as long as motor units were undergoing recruitment. Variation of the firing rate after all the motor units were already active resulted in unchanged MF, which tended to decrease as fatigue started to set in. It was concluded that it may be

possible to identify the control strategy of various muscles when subjected to linearly-increased contraction while monitoring the EMG's MF.

**Preliminary Results**—Preliminary data obtained from human subjects under voluntary control of different muscles confirm the results obtained from the animals subjected to electrical stimulation.

#### **Publications Resulting from This Research**

None reported.

### **[236] A Method for Controlling Muscle Contraction Under Orderly Stimulation of Motor Units with Tripolar Nerve Cuff Electrodes**

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**Sponsor:** *National Science Foundation*

**Purpose**—The use of functional electrical stimulation to elicit muscle contraction has been plagued by the use of various control strategies which result in non-physiological activation in reverse recruitment of motor units (large-to-small units as opposed to the physiological small-to-large mode), random recruitment, or modulation of firing rate only. Such approaches result in non-linear force response, large initial forces, fast onset of fatigue, and the need to use high firing rates to avoid twitched (unfused) initial forces, which further accelerates fatigue and renders the contraction useless for any practical purpose.

Attempts to elicit orderly recruitment with anodal DC block exposed the muscle to permanent damage, while application of pulsed hyperpolarization block seems to work only for twitched (unfused) contraction, while producing large noise and potentiation at moderate-to-high discharge rates. Both techniques seem useless for practical purposes.

**Progress**—Over the past 11 years, we have developed a stimulation technique which is capable of

recruiting motor units in an average orderly fashion, small units first, and progressively larger ones, while simultaneously, but independently, varying the active units firing rate in a similar mode to various known control strategies. The technique uses two bipolar electrodes placed on the muscle nerve with the high-frequency block as the operating principle.

**Results**—Recent work reduced the electrodes requirement from two bipolar cuffs to a single tripolar cuff. The technique was reevaluated and demonstrated orderly recruitment with concurrent firing rate control from the fatigue, conduction velocity, and twitch characteristic principles.

#### **Publications Resulting from This Research**

**Manipulation of Muscle Force with Various Firing Rates and Recruitment Control Strategies.** Zhou B, Baratta R, Solomonow M, *IEEE Trans Biomed Eng* 34:6-18, 1987.

**A Method for Studying Muscle Properties Under Orderly Stimulation of Motor Units with Tripolar Nerve Cuff Electrodes.** Baratta R, Ichie M, Hwang S, Solomonow M, *J Biomed Eng* 11:141-147, 1989.

**Orderly Stimulation of Skeletal Muscle Motor Units with Tripolar Nerve Cuff Electrodes.** Baratta R, Ichie M, Hwang S, Solomonow M, *IEEE Trans Biomed Eng* 36:836-843, 1989.



## [237] Inhibition of Stretch Reflexes Using Electrical Stimulation in Normal Subjects and Subjects with Spasticity

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Sponsor: *Natural Sciences and Engineering Research Council of Canada*

**Purpose**—The stretch reflex is one of the crucial spinal mechanisms used by the central nervous system for the fine coordination of movements in performing mechanical tasks. An exaggerated stretch reflex is a primary indicator for the presence of a neurological disorder such as cerebral palsy or multiple sclerosis. In this work, the potential of using electrical stimulation as a means for reducing spasticity was investigated.

**Methodology**—An apparatus was developed which can impose controllable mechanical perturbations at the ankle joint in order to elicit the stretch reflex in the soleus muscle. The instrument can impose rotary movements at the ankle joint, thus causing a stretch in the soleus muscle.

The integrated electromyographic (IEMG) activity of the soleus muscle is measured through surface electrodes and amplified using differential amplifiers. Furthermore, a controllable electro-stimulator may deliver electrical pulses to the antagonist muscle. All devices are computer controlled and all data are sampled and stored in the memory of the digital computer.

Two types of experiments were performed on all subjects. The first is referred to as the exploratory experiment. It consists of applying a burst of stimulation to the tibialis anterior muscle at a variable latency relative to the mechanical disturbance applied at the ankle joint. The mechanical disturbance usually causes a stretch reflex IEMG to be measured from the soleus muscle. The purpose of the exploratory experiment is to determine whether electrical stimulation applied at a specific time before the mechanical disturbance will cause inhibition of the stretch reflex. The second experiment is the comparative one. In this experiment, the latency at which the stimulation is found to be most effective in inhibiting the stretch reflex observed during the exploratory experiment is used to obtain a larger statistical sample of its effects and to determine whether this effect is significant.

**Results**—From the exploratory experiment, it was evident that the electrical stimulation caused a considerable reduction in the stretch reflex. It was found that the most effective time for this inhibition is approximately 160 ms before the onset of the disturbance. A comparative experiment was then performed. In 6 normal subjects, inhibition ranged from 50 percent to 86 percent.

The same experiments were performed on 6 subjects with spasticity arising from cerebral palsy, multiple sclerosis, and spinal cord injury. In one subject with cerebral palsy the effect of the stimulation was to cause an inhibition of 48 percent in the left side and 30 percent in the right side. This inhibition was quantified using only the first burst of activity. Clonus was almost eliminated in this subject. Inhibition was not consistent in all 6 subjects however. The second cerebral palsy subject did not show any inhibition. In the spinal cord injury cases, inhibition was evident but not in the level of clonus. As for multiple sclerosis, good levels of inhibition were attained. Altogether, in those subjects in whom inhibition was possible, the range was from 20 percent to 76 percent with inhibition being most effective in the multiple sclerosis cases.

**Future Plans/Implications**—It was found that electrical stimulation of the antagonist muscle causes inhibition of the stretch reflex in both normal subjects as well as exaggerated stretch reflexes and clonus in subjects with spasticity. This inhibitory phenomenon may prove useful in designing electronic orthoses for patients with spasticity. The next step in this research is to identify optimal stimulus parameters which may reduce spasticity during gait.

### Publications Resulting from this Research

**Inhibition of Soleus Muscle Stretch Reflexes Through Antagonist Electrical Stimulation in Normal Subjects and Subjects with Spasticity.** Apkarian J, Naumann S, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 177-178, 1989.



## [238] Modeling and Identification of Electrically-Stimulated Muscle

**William K. Durfee, PhD**

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**Sponsor:** *Whitaker Foundation*

**Purpose**—In this project, we are using animal preparations and human subject experiments to develop better models of electrically-stimulated muscle. In particular, we are interested in how stimulated muscle force varies with stimulation activation, muscle length, muscle velocity, and muscle fatigue. A secondary goal is to develop rapid identification procedures for parameterizing the muscle models. Our goal is to use these models in designing controllers for functional electrical stimulation (FES) systems which restore gait and grasp.

**Progress**—In a series of animal experiments we have developed a novel means for identifying the isometric recruitment curve of electrically-stimulated muscle. This new method is a factor of ten faster, and provides more resolution than traditional tech-

niques. Knowledge of the isometric recruitment curve is crucial in designing effective, open, or closed-loop controllers for FES systems.

**Future Plans**—We are embarking on a series of experiments to identify the muscle force-length and force-velocity properties using nonlinear system identification techniques. These techniques will be developed in simulation, in animal preparations, and in human subject experiments.

### Publications Resulting from This Research

**Task-Based Control with an Electrically Stimulated Antagonist Muscle Pair.** Durfee W, *IEEE Trans Biomed Eng BME-36(3)*:309-321, 1989.

**Methods for Estimating Isometric Recruitment Curves of Electrically Stimulated Muscle.** Durfee W, MacLean K, *IEEE Trans Biomed Eng BME-36(7)*:654-667, 1989.

## [239] Muscle Stimulation Strategies for High Contact Density Microstimulation Electrodes

**William K. Durfee, PhD**

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**Sponsor:** *Whitaker Foundation (Health Science Fund)*

**Purpose**—There is a striking contrast between the normal, physiologic activation of muscle by the central nervous system (CNS) and activation of a muscle by functional electrical stimulation (FES). Artificially-induced contractions fatigue rapidly, are difficult to modulate for fine control, and demonstrate gross variation over short time-scales. One of the causes for this difference is the neural interface through which the muscles are activated. The CNS has access to the motor neuron pool of hundreds or thousands of motor units per muscle, which it modulates both by recruitment and by timing sequences to produce smooth, low-fatiguing contractions for finely-controlled motion. In contrast, artificial stimulation is generally achieved with a single, gross electrode either wrapped around the peripheral nerve or applied over the surface of the muscle. Here, all muscle fibers are activated syn-

chronously at high, fatiguing, stimulation frequencies to avoid muscle force ripple and with almost no control over individual motor units, resulting in an undesirable large-to-small motor unit recruitment order.

Recent advances in very large scale integration (VLSI) technology have led to the miniaturization of electronic components and opens the possibility of designing new neural stimulation interfaces which can contain hundreds or even thousands of electrode contacts, each of which could uniquely activate one or a few motor units. The goal of the research proposed here is not to develop this electrode technology, but rather to determine how these future, high contact density, nerve stimulation electrodes should be used to effectively recruit muscle activation in FES applications.



**Progress/Methodology**—This is a new project and we are developing the experimental equipment and techniques for testing potential stimulation algorithms. Our approach will be to create a relatively crude, multiple channel nerve interface which will permit us to test microstimulation algorithms in an appropriate animal model. We envision an acute preparation which connects with 5 to 20 axons.

Along with exploring stimulation algorithms, we will develop identification procedures for determining the type of motor unit or units connected to each electrode contact.

#### **Publications Resulting from This Research**

None reported.

### **[240] Rehabilitation Engineering Center for Restoration of Neural Control**

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**P. Hunter Peckham, PhD; Michael W. Keith, MD**

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MetroHealth Medical Center, Cleveland, OH 44109

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

#### **Program Overview**

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**Purpose**—The objectives of the Rehabilitation Engineering Center for Functional Electrical Stimulation at Case Western Reserve University (CWRU-REC) are to: 1) develop, test, implement, and evaluate clinical systems employing functional electrical stimulation (FES) technology that provide control of the extremities, stabilization of the trunk, and function of the respiratory and urinary systems; 2) establish a model information exchange program providing information on FES for consumers, medical care providers, third-party payers and manufacturers; 3) deploy FES systems to other rehabilitation and research institutions; and, 4) transfer FES technology to private industry.

FES can be used in several ways to effect control of the nervous system. It can control abnormal motor system function resulting from stroke, head injury, cerebral palsy, or scoliosis. It can also restore motor and sensory function loss due

to paralysis resulting from spinal cord injury or stroke. In this program, we will address the problems presented by individuals with these injuries.

The program is organized to promote investigation in six priority areas: 1) development of a comprehensive FES information collection, referral, and dissemination program; 2) upper extremity FES and hybrid systems for manipulation and grasp; 3) systems employing FES and orthotics to stabilize the trunk and correct trunk deformities; 4) control of spasticity in stroke and head injury by FES; 5) control of respiration in central respiratory insufficiency; and, 6) control of micturition in the neurogenic bladder by FES.

The first project is one of information and collation and dissemination. The remaining projects involve clinical implementation to restore functional control.

### **[241] Development of Functional Electrical Stimulation Information Center Database and Dissemination Service**

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**Geoffrey B. Thrope, BS; Jeanne Teeter**

**Purpose**—The mission of the FES Information Center is to serve as national resource on FES technology providing information ranging from an introductory overview of FES to on-line computer-based literature searches.

The first objective of this project is to develop and maintain a comprehensive information database on FES which will include scientific findings and forums, journal articles, reprints from proceedings, progress reports, educational seminars and an-



nouncement dates, material relevant to manufacturers and researchers regarding equipment, articles relevant to direct and nondirect health care providers, and a glossary of FES terms applicable to the scientific, medical, and consumer communities.

The second objective is to develop the means to disseminate the information in an accessible format to the following targeted population: persons with disabilities, clinicians, independent living programs, counselors, third-party payers, researchers, and manufacturers interested in the area of FES.

The third objective is to develop a presentation format which collates the work of multiple investigators and facilities throughout the world and allows a clear view of the coordination and interrelationship among these efforts and the products they generate.

**Methodology**—The term FES within the context of this section refers in particular to all applications of neuromuscular stimulation resulting in restoration of motor function. These areas will include FES applied to the restoration of upper and lower extremity function, bladder control, diaphragmatic pacing, and therapeutic utilization of FES applied to range of motion, muscle strengthening, and muscle re-education. Examples of areas that will not be stressed in this program are traditional cardiac pacing and control of pain using transcutaneous nerve stimulation (TENS).

It is implicit to this project that the information that is collected and collated be nonpartial and nonparochial in nature. The collected information should include relevant documents from an international community of FES researchers and manufac-

turers of FES devices. Therefore, within the working definition of FES and its application toward restoration of neuromuscular function, we intend to include all relevant information helpful to the named targeted population groups.

**Progress**—The major goals for the second year of the FES Information Center are on schedule. The activities that have engaged the bulk of our time have been in development of our library facilities and development of our information request processing program.

We have developed a national Core Contact Committee, consisting of representative members of our targeted client populations, to assist in reviewing Information Center procedures and publications. Recently, we began supporting an electronic Bulletin Board Service (BBS), called FES-NET (1-216-368-2947, 2400 baud, 8-bit, no parity), in conjunction with the other CWRU-REC programs. The BBS provides another method of accessing the FES Research Directory, the Calendar of Events, and the information request services of the Information Center. As of August 31, 1989, we received 181 requests through our 1-800-666-2353 phone service for information from disabled consumers, clinicians, researchers, manufacturers and third-party payers, and other service providers. Thus far, we have processed 176 of those requests. We anticipate that future request activity levels will conservatively be at least 50 requests per month.

#### **Publications Resulting from This Research**

None reported.

### **[242] Development of Upper Extremity Control Employing Functional Electrical Stimulation**

**P. Hunter Peckham, PhD; Michael W. Keith, MD; Geoffrey B. Thrope, BS**

**Purpose**—The objective of this project is to clinically evaluate the efficacy of FES hand systems which provide restoration of grasp and release for the high level spinal cord injured individual. The first systems to be evaluated have been developed at the C5 and C6 level quadriplegic to regain control of two prehension patterns, palmar and lateral prehension, through chronically indwelling percutaneous

electrodes. We will transfer this technology to four Centers in addition to our own and perform carefully regulated and supervised trials to validate the findings in our own research. The four Satellite Centers are: 1) University of Alberta, Edmonton; 2) University of Toronto, Hugh MacMillan Rehabilitation Engineering Centre, Lyndhurst Hospital, Toronto; 3) Shriners Hospital, Philadelphia; and, 4)



Rancho Rehabilitation Engineering Program, Los Angeles.

As a result of these studies, we will evaluate the level of functional hand control that can be restored to the high level quadriplegic patient, and identify limitations in transferability of implementation at other Centers. We will use identical measurement methodology to evaluate in controlled studies at each Center the efficacy of these systems in providing enhanced independence in activities of daily living and quantitatively measured tasks, and document the reliability of the system and sources of failure.

**Progress**—Progress for the second year of this project has proceeded satisfactorily. The major goals and objectives that have been identified through the second year of this project are:

*Refinement of Protocols for Implementation and Evaluation.* The two major aspects of the FES Hand System program are divided into Implementation and Evaluation. These phases required our team to intensively scrutinize our practices and means for accomplishing these tasks in order to develop and write the protocols necessary for other Centers to use in order for their programs to be successful.

*Standardizing Hardware/Software and Supportive Devices.* Our team had to devise a plan for uniform methodology for all Centers to follow in implementing the hand systems in subjects. Therefore, all software used in the programming of the systems, all components of the upper extremity devices, and peripheral support devices had to be

manufactured by our Center so that all Centers would be using the same means to accomplish the task of having a subject's hand system become functional.

*Uniform System Characteristics.* 1) The systems must be portable so that an investigator may program and/or refine the subject's hand system at a remote site, and not only in the confines of the laboratory; 2) the systems must be transferrable to all Centers in a manner whereby others can learn to use the systems without encumbering the primary CWRU Center for continued assistance in order to have the technology perform properly; 3) the systems have to be expandable in the future so that new technology that either would be required to enhance the system based upon field observations, or general enhancements which would better facilitate the process, could be incorporated within the existing systems without making the devices obsolete; 4) the systems have to perform with minimal maintenance in order to have as little downtime as possible for the subjects; 5) there must be an appropriate number of systems available when the Centers are ready to begin working with subjects; and, 6) the goal of the program has become to implement and evaluate three subjects at each of the four remote Centers.

To date, we have accomplished the majority of preliminary objectives and are now working toward implementing systems with subjects and evaluating their performance.

#### **Publications Resulting from This Research**

None reported.

### **[243] Electrical Stimulation in the Treatment of Scoliosis**

J. Thomas Mortimer, PhD; Clyde L. Nash, MD; Peter V. Scoles, MD; Laurel S. Mendelson, MS

**Purpose**—The purpose of this study is to determine the efficacy of treating adolescent idiopathic scoliosis by electrical activation of the deep paraspinal muscles on the concave side of the curve. Prior investigations have demonstrated that at least one group of these muscles, the multifidi, are longer and less active on the concave side of the curve than on the convex side. In this study, we will measure the effect on spinal curvature of increasing the

activity and decreasing the length of the multifidus muscles on the concave side of the curve. The device that will be used to activate these muscles is a percutaneous, multichannel, neuromuscular stimulator that was developed in our laboratory.

**Methodology**—Fifteen adolescent subjects with idiopathic scoliosis will participate in this pilot study. Each will have three helically wound wire electrodes



inserted percutaneously into the deep paraspinal muscles on the concave side of the curve. Electrical stimulation will be applied to the electrodes throughout the day in a pattern of 4 hours on and 2 hours off. Curve correction will be monitored by inspection and by periodic radiographs. In the event of curve progression, the electrodes will be removed and the patient transferred to the Milwaukee brace program.

Each subject will participate in this study from the time of diagnosis until skeletal maturity (approximately 2 years), and will be followed for at least 1 year after stimulation has ended.

**Progress**—Progress on this project has been in the areas of device design and construction, investigation of electrode placement, and fulfillment of regulatory requirements.

*Device Design and Construction.* A microprocessor controlled laboratory stimulator that was used in chronic animal studies for many years was redesigned for clinical applications. The stimulator is an intelligent, battery powered, 4-channel system. It allows variable control of stimulus pulse-width, amplitude, interpulse interval, frequency, and timing. The output is a regulated current, balanced charge, biphasic stimulus. To date, 5 stimulators have been built and tested. Each unit weighs 300 grams (10.7 ounces) and has dimensions of approximately 6×4×1 inches. The stimulators are powered by 2 size C lithium batteries, and have lifetimes of 6

to 8 weeks. A new connector was designed to attach the electrodes to the stimulator cabling. The connector is molded from silicone rubber in order to minimize discomfort during sleep. To date, 100 connectors have been fabricated.

*Investigation of Electrode Placement.* Intraoperative studies are underway to determine the innervation of the multifidus muscles in the thoracic region and to locate optimal electrode placement to elicit muscle contraction. The pattern of innervation we have thus observed is for the motor nerve to enter the multifidus near the point (within 5-10 mm) where the muscle inserts onto the spinous process.

*Fulfillment of Regulatory Requirements.* A large amount of our recent work has involved preparing the documentation for institutional review board approval and for an investigational device exemption from the Food and Drug Administration (FDA). At the present time, we have received institutional approval for all of our studies at University Hospitals and Saint Luke's Hospital, in Cleveland, Ohio.

**Future Plans**—In the near future, we plan to receive FDA approval to begin our investigation of scoliosis treatment. In the upcoming year, we will finalize the equipment needed for the clinical study and begin to evaluate treatment results in 3 to 5 patients.

#### **Publications Resulting from This Research**

None reported.

## **[244] Characterization and Reduction of Spasticity by Stimulation in the Hemiplegic Upper Extremity**

Patrick E. Crago, PhD; Peter Gorman, MD

**Purpose**—The goal of this study is to improve upper extremity function in patients with hemiplegia by reducing spasticity and improving voluntary control by electrical stimulation. Electrical stimulation of finger and thumb extensor muscles of the ulnar nerve is expected to reduce resting activity levels in spastic muscles and to increase voluntary control. The effects of stimulation will be quantified by measurement of the electromyographic activity in the stimulated muscles and in muscles representing the major flexor and extensor groups of the fingers,

the thumb, and the elbow. Effects of stimulation will also be quantified by measuring the kinematics of voluntary and stimulus-induced movements at the fingers, thumb, wrist, and elbow.

Quantification of spasticity by measurement of the increased resistance to joint rotation (stiffness) is frequently complicated by changes in initial conditions. If this dependence can be quantified and if it is repeatable, then spasticity and therapeutic methods may be measured more easily. The dependence of stiffness on the initial activation levels of co-



contracting antagonists will be measured both in normals and in subjects with spasticity. A technique will be used that enables the separation of mechanical and reflex components of the stiffness. This technique will also be used to further characterize the effects of stimulation on the reflex sensitivity to

stretch and allow future improvements of methods to reduce spasticity.

#### **Publications Resulting from This Research**

None reported.

### **[245] A Micturition Assist Device**

**J. Thomas Mortimer, PhD; Donald R. Bodner, MD; James D. Sweeney, PhD; James M. Martau, BS**

**Purpose**—The purpose of this research is to implement a technique to block peripheral nerve transmission in order to treat hyperreflexic bladder paralysis in spinal cord injured patients. The technique is based on implanting a cuff electrode around the peripheral nerves that control the external urinary sphincter. The cuff is capable of electrically inducing a unidirectional action potential that can collide with and annihilate the hyperreflexic signal propagated along the pudendal nerve. Combined with detrusor muscle excitation, collision block of neural traffic along the pudendal nerves should effect a reduction in the urethral resistance that would permit voiding of urine from the bladder.

**Methodology**—Asymmetric two-electrode cuffs (ATEC) designed to propagate action potentials in only one direction were implanted around the pudendal nerves in 3 dogs. A regulated current quasi-trapezoidal biphasic stimulus was used as the blocking stimulus. Current amplitude, phase width, and exponential decay were varied to find the operating point, or the set of parameters that most effectively block the axons while minimizing the total charge injection. Axon blockage is evaluated by measuring the change in resting pressure in the urethral sphincter and the bladder.

**Progress**—The effectiveness and safety of unilateral pudendal ATECs has been evaluated after 2 weeks and 4 weeks of implantation. An apparent temporal pressure block of large fiber conduction in the implanted nerve trunks produced distinctive differences between the 2-week and 4-week tests in all 3 animals. In two of the implants, significant nerve trunk tissue damage, presumably due to surgical trauma and/or cuff encapsulation, decreased the

effectiveness of ATEC function; in the third implant, virtually no damage was detected and ATEC effectiveness was high.

The ability of the ATEC to block peripheral nerve transmission with unidirectional action potentials has been established. However, for chronic application, it is essential to minimize charge injection since tissue damage is related to the electrochemical reactions occurring on the electrode surface. Since the ATEC is physically larger and injects more charge than other electrodes, the reaction of the pudendal nerve to the stimulus must be determined.

**Preliminary Results/Implications**—At the present time, 3 dogs have received pudendal implants. Each of the dogs is tested every 3 weeks to evaluate changes in the operating point. Although the testing is still continuing, the data suggest no evidence of an increase in the charge required for effective blocking from one test to another. In addition, encapsulation of the ATEC does not appear to cause damage to the nerve.

**Future Plans**—In the near future, cuff electrodes will be implanted on the ipsilateral side. At the end of the study, the dogs will be sacrificed and the histology of the nerve will be evaluated.

#### **Publications Resulting from This Research**

**An Implantable Cuff Electrode for Collision Block of Pudendal Nerve Motor Activity.** Mortimer JT, Sweeney JD, Bodner DR, Ferguson AS, in *Proceedings of the 10th Annual IEEE/EMBS Conference*, New Orleans, LA, 1523-1524, 1988.

**Collision Block of Motor Activity in Peripheral Nerve.** Sweeney JD, in *Proceedings of the World Congress on Medical Physics and Biomedical Engineering, Physics in Medicine and Biology*, 33(1):162, 1988.



**Acute Animal Studies on Electrically Induced Collision Block of Pudendal Nerve Motor Activity.** Sweeney JD, Mortimer JT, Bodner DR, *Neurol Urodyn* (accepted for publication).

**Animal Study of Pudendal Nerve Cuff Electrode Implants for Collision Block of Motor Activity.** Sweeney JD, Mortimer JT, Bodner DR, *Neurol Urodyn* (accepted for publication).

## B. Upper Limb Applications

### [246] Functional Neuromuscular Systems for Upper Extremity Control

**P. Hunter Peckham, PhD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B011-3RA)

**Purpose**—The objective of this project is to implement a neuroprosthetic system which restores motor control in the paralyzed upper extremity of the high-level spinal cord injury patient. The system provides controlled grasp release by electrical stimulation of the paralyzed muscles in the forearm and hand, thereby improving the user's ability to independently perform activities of daily living. Percutaneous electrodes are used first; later, they progress to an implantable receiver/stimulator system as performance and usage of the hand system is demonstrated.

**Progress**—Progress has been made to provide portable neuroprosthetic systems for outpatient use, for development of communication and interface between laboratory computers and portable systems, and in fabrication of implantable systems.

Two aspects of neuroprosthetic system fabrication are underway: fabrication of devices in-house for patient usage (eight such units have been completed), and completion of all hardware modifications and documentation necessary to transfer the device to a commercial manufacturer. The portable electronics module, cabling and connector interfaces for transducer units and electrode cables have been received from a commercial manufacturer.

Fabrication of the communication-to-interface is complete, enabling programming of the system through a personal computer and extraction of control and usage information.

Amplitude control for the implant unit, is completed and implemented, providing four levels of amplitude selection over the range up to 20 mA in

addition to pulse width and stimulus period modulation.

Design of the implanted intramuscular electrode has been completed; animal evaluation is underway in conjunction with two implanted stimulator units. Animal evaluation of the receiver/stimulator continues with three animals implanted and undergoing periodic monitoring. One animal has eight epimysial electrodes; the other two have four epimysial and four intramuscular electrodes. The longest implant in an animal is at 3 years with evidence of satisfactory operation.

**Results**—At present, there are 6 patients; all upper extremity users. Two new patients started in the past year, but withdrew because of a serious illness in the family.

Clinical evaluation of system performance focused on three primary aspects of quantitative assessment of system usage. The tests employed are the Common Object Test (COT), Standardized Object Test (SOT), and Subsystem Function Test (SFT). The COT measures function in acquiring and using objects of daily living. The SOT standardizes performance and repetitive acquisition of six uniform objectives. The SFT enables quantitating user operation during in-laboratory testing by identifying elements of the system which are affecting performance.

An evaluation of patients' abilities with and without the functional neuromuscular stimulation (FNS) system was performed using interviews with patients to determine usage retrospectively. Results showed an 89 percent rate with the FNS system; 49



percent without. C5 subjects benefited more than C6. These studies are being continued in more extensive COT testing.

During SOT evaluation, repetitive object acquisition is performed over several sequential trials. The SOT detects significant changes in consistency of patient performance over time, differences in performance across patients, and differences in performance with and without the hand system.

The subsystem function tests have been developed to quantitatively evaluate and document the system input/output properties, patient control of hand grasp, and frequency response of the man-machine system. The hand grasp outputs are position and force generated by the thumb during lateral prehension or the fingers during palmar prehension. The input to the neuroprosthesis is a command signal generated by voluntary movement of the patient's shoulder.

Each test uses a visual pursuit tracking task. A target track and system output are displayed simultaneously on a color video display. The subject is asked to match the output to the track as accurately as possible. System output is defined as a single parameter formed by summing grasp opening (position) and normalized grasp force.

In addition to the quantitative assessments, a psychological evaluation protocol has been introduced to profile the characteristics of our user population. In 1988, the implantable receiver/stimulator in a study subject was replaced. All original electrode leads were completely intact with reconnection made at the in-line connectors. Subsequent laboratory evaluation of the implanted unit identified a weld connection at the antenna as the source of the higher power consumption. Subsequent modification of the antenna design eliminated this source of potential problem for future implants. The subject continues to use the system in daily activities.

**Future Plans**—Approval was obtained from the Food and Drug Administration to carry out the

study of 10 subjects with the implanted system. This protocol will enable us to use the devices manufactured in-house for this study. Transfer of the external patient portable system (NPS-IV) to a local manufacturer is well underway. A manufacturer has been identified to fabricate 8-channel implantable devices under the fabrication guidelines.

### Publications Resulting from This Research

- Functional Activation of the Paralyzed Extremities.** Peckham PH, in *Encyclopedia of Neuroscience*, 916-919, G. Adelman (Ed.), Boston: Birkhauser Boston, Inc., 1987.
- Functional Electrical Stimulation: Current Status and Future Prospects of Applications to the Neuromuscular System in Spinal Cord Injury.** Peckham PH, *Paraplegia* 25(3):274-288, 1987.
- An Externally Powered, Multichannel Implantable Stimulator for Versatile Control of Paralyzed Muscle.** Smith B, Peckham PH, *IEEE Trans Biomed Eng* BME-34(7):499-508, 1987.
- Functional Electrical Stimulation.** Peckham PH, in *Encyclopedia of Medical Devices and Instrumentation*, 1331-1352, J. Webster (Ed.), New York: John Wiley & Sons, 1987.
- Current Concepts Review: Restoration of Functional Control by Electrical Stimulation in the Upper Extremity of the Quadriplegic Patient.** Peckham PH, Keith MW, Freehafer AA, *J Bone Joint Surg* 70A(1):144-148, 1988.
- Functional Neuromuscular Stimulation Neuroprostheses for the Tetraplegic Hand.** Keith MW, Peckham PH, Thrope GB, Buckett JR, Stroh KC, Menger V, *Clin Orthop* 233:25-33, 1988.
- A Flexible, Portable Functional Neuromuscular Stimulation Neuroprosthetic System.** Buckett JR, Peckham PH, Thrope GB, Braswell SD, Keith MW, *IEEE Trans Biomed Eng* 35(11):897-904, 1988.
- New Concepts on Treatment of the Upper Limb in the Tetraplegic: Surgical Restoration and Functional Neuromuscular Stimulation.** Freehafer AA, Peckham PH, Keith MW, in *Hand Clinics*, 4(4):563-574, Raoul Tubiana (Ed.), Philadelphia: W.B. Saunders Company, 1988.
- Implantable Functional Neuromuscular Stimulation in the Tetraplegic Hand.** Keith MW, Peckham PH, Thrope GB, Stroh KC, Smith B, Buckett JR, Kilgore KL, Jatich JW, *J Hand Surg* 14A(3):524-530, 1989.
- Synthesis of Hand Movement Using Functional Neuromuscular Stimulation.** Kilgore KL, Peckham PH, Thrope GB, Keith MW, *IEEE Trans Biomed Eng* 36(7):761-770, 1989.
- Force Vector Recruitment of Electrically Stimulated Paralyzed Thenar Muscles with Application to Functional Neuromuscular Stimulation.** Kilgore K, Peckham PH, Keith MW, *IEEE Trans Biomed Eng* (accepted for publication).



## [247] Evaluation of Command Channels for Upper Limb Neural Prostheses

**William K. Durfee, PhD**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Upper limb neural prostheses use electrical stimulation to restore grasping function to quadriplegics. The user of such a system must have a signal channel to command the device to open and close the hand. The most common method for generating a command signal is to monitor motion of the contralateral shoulder. This project has the objective of: 1) exploring the limits on performance of upper limb neural prostheses imposed by the command channel; 2) evaluating novel command channels, such as electromyography (EMG); and, 3) developing assessment and prescription systems for optimizing command channel parameters for a particular user.

The basic approach is through an emulator of an FES hand grasp system. Subjects sit in front of a personal computer and the appropriate command channel being tested is monitored. For example, a sternum-mounted position sensor is used to detect shoulder position. An animation of a grasping task appears on the personal computer display. As the subject moves his real hand, the hand on the screen moves; as the subject manipulates his command channel, the animated hand opens and closes. The subject performs a simulated grasping task by manipulating and moving objects that appear on the screen. Performance is measured by the speed and dexterity with which the task is performed. The

advantage of this emulator system is that parameters of the command channel can be changed while keeping the task constant, resulting in efficient cross comparisons.

**Progress**—We have conducted a series of tests of the shoulder as a command channel in both able-bodied and quadriplegic subjects. The results demonstrate that optimal combination of shoulder command channel parameters, such as direction and range, vary with individual subjects. This suggests the need for a prescription system which can evaluate each subject and determine the appropriate combination.

We have also conducted a preliminary study of EMG as a command channel using able-bodied subjects. Results show that sufficient information transfer is possible with EMG, but at a reduced bandwidth.

**Future Plans**—We are currently developing a low-cost prescription system based on personal computers which would allow a clinic to evaluate shoulder command channel modalities.

### **Publications Resulting from This Research**

**Command Channels for Upper Limb Neural Prostheses.** Durfee W, Mariano T, in *Proceedings of the 10th Annual RESNA Conference*, San Jose, CA, 624-626, 1987.

## [248] Effect of Functional Electrical Stimulation Parameters on CVA Shoulder Pain

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VA Medical Center, Knoxville, IA 50138

**Sponsor:** *None listed*

**Purpose**—This study proposed to be useful in facilitating functional electrical stimulation (FES) utilization in designated optimum parameters for pain reduction in the cerebrovascular accident

(CVA) painful shoulder. If proven, benefits to the patient would be: 1) reduction of pain, thus increased patient comfort; 2) increased range of motion (ROM) in the shoulder, making it possible



for the patient to move the arm if and when the muscle attained re-education; and, 3) increased ROM for better patient hygiene.

**Progress**—The study compared one group of CVA patients treated with FES (test subjects) to control subjects treated with standard hot packs. Both groups were subsequently provided standard ROM exercises and other therapy appropriate to their disability. Subjects were selected from the Rehabilitation Unit of VAMC Knoxville, IA, based upon the following criteria: treatment beginning 2–8 weeks post-CVA; pain of central origin rather than “all over” type pain; and, absence of previous history of shoulder joint pathology causing restriction of shoulder joint ROM. Exclusion criteria: patients with cardiac pacemakers or with history of cardiac conduction problems; and, patients with dementia or verbal dysfunction.

**Methodology**—Patients were assigned to an experimental group or a control group at random. All patients signed a consent form to participate. Dependent variables were then recorded weekly for four weeks as follows: 1) patient’s description of any change in pain according to the Simple Descriptive Scale (SDS); and, 2) comparative ROM measurements of shoulder flexion-extension, internal and external rotation and abduction-adduction. One

pair of FES electrodes was placed over the anterior and middle deltoid muscles with 1-inch space between, and a second pair was placed over the posterior deltoid and supraspinatus muscles. An alternating mode of current was used as tolerated.

**Results**—Results from this study of 9 patients suggested that FES has a significant value in the reduction of CVA shoulder pain. Subjective clinical observations using the SDS resulted in 66 percent perceived pain reductions in the subjects treated with FES. Those receiving hydrocollator application reported the same percentage of pain reduction (66 percent). Objective measurement of ROM resulted in an average overall increase of 24 degrees per patient treated with FES, compared with an average overall increase of 47 degrees in patients treated with standard protocol hydrocollator application. The FES approach to CVA shoulder pain reduction was technically successful in all cases studied. However, it was not as successful as the hydrocollator packs. This outcome supports two tentative conclusions: 1) the FES technique can be a practical clinical method for reduction of CVA shoulder pain; and, 2) FES may be a valid alternative treatment when the use of heat (hydrocollator packs) is contraindicated.

#### **Publications Resulting from This Research**

None reported.

### **[249] Electromyography (EMG) as a Feedback Parameter in a Closed-Loop FES System**

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**Sponsor:** *National Science Foundation*

**Purpose**—The use of force feedback in an electrical muscle stimulation system for the paralyzed may be essential for fine, accurate control of upper extremity joints. Unfortunately, monitoring *in vivo* force requires that the muscle tendon will be severed and a force transducer placed in series with the muscle, an option which is not acceptable in humans. It is the objective of this long-term study to explore the feasibility of the EMG recorded from the stimulated

muscle to reliably predict force, a procedure which is noninvasive and highly flexible.

**Progress**—Previous studies determined the feasibility of this new approach, tested several potential signal-processing methods for the EMG, and delineated the use of the EMG feedback under several stimulation control strategies. Current efforts studied the impact of a wide range of contraction rates



(force generation rate), and muscle fiber composition on the EMG-force relationships, and the most recent study delineated the effect of changing joint angle/muscle length on the EMG to force transformation.

**Results**—It is apparent that the EMG does not predict muscle force in a direct manner, but depends on various other factors that must be considered carefully in the transformation model. Such factors include muscle fiber type, stimulation control strat-

egy, contraction rate, muscle length, and the muscle's moment arm about the joint.

### Publications Resulting from This Research

**The EMG-Force Model of Electrically Stimulated Muscle: Dependence on Control Strategy and Predominant Fiber Composition.** Solomonow M, Baratta R, Zhou B, Shoji H, D'Ambrosia R, *IEEE Trans Biomed Eng* 34:692-703, 1987.

**The Impact of Contraction Rate and Control Strategy on the EMG-Force Relationships.** Solomonow M, Baratta R, Shoji H, D'Ambrosia R, *EMG Clin Neurophys* (in press).

## C. Lower Limb Applications

### [250] Computer Models for Designing FES Systems for Paraplegic Mobility

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B299-2RA)

**Purpose**—The long-term objective of this project is to develop computer tools to assist the rehabilitation team in designing user-specific functional electrical stimulation (FES) control systems so that paraplegics can stand, walk, and perform other lower-extremity motor tasks.

**Methodology**—The dynamic equations of body segments for standing, walking, and other motor tasks important to the paraplegic will be generated and implemented on a computer. The musculoskeletal system will be modeled including paths of lower extremity musculotendon actuators. The dynamics associated with these actuators will be computer coded.

A procedure will be developed to generate computer code so models can easily be constructed, thus making it possible to study a variety of lower limb motor tasks. Computer code will be generated to display on a workstation the computer simulations of FES-induced standing, walking, and the other motor tasks.

**Progress**—We have developed a computer model of 2-D standing assuming bilateral symmetry. A multi-

input/multi-output feedback control law was found that assumes the body segmental orientations; angular velocities are measured or estimated. The feedback control determines the stimuli to be applied to the lower-extremity muscles. With this feedback controller, our simulations show that the body will move to the upright position even when disturbances are encountered (such as unexpected arm movements) or the body is initially away from the upright position, such as in the seated position. The simulations have been implemented on a workstation and show that the controller acts very well.

**Results**—We have developed a 3-D, 8-degree-of-freedom dynamic model of walking. Dynamic programming and an open-loop, trial-and-error adjustment process was used to find muscle stimulation patterns to sustain a step. Using this approach, we have concluded that functional neuromuscular stimulation (FNS) assisted bipedal level gait at normal speeds, though extremely difficult, would be possible if the electrically stimulated ankle plantar flexors exhibit either near-normal strength or are augmented by an orthosis.



An ankle-foot orthosis would be of extreme advantage as it would also help to stabilize the stance leg and would simplify control during swing. The simulated walk was also implemented on the workstation. We found that such graphic displays of walking assist in judging whether an adequate simulation has indeed been found.

### Publications Resulting from This Research

**Computer Model and Control-System Design of Paraplegic Standing Controlled by Functional Neuromuscular Stimulation.** Khang G, Zajac FE, in *Modeling and Control Issues in Biomechanical Systems, 1988 ASME Winter Annual Meeting in Chicago*, DSC(12):45-54, J.L. Stein (Ed.), New York: The American Society of Mechanical Engineers, 1988.

**Intersegmental and Mass Center Accelerations Induced by Lower Extremity Muscles: Theory and Methodology with Emphasis on Quasi-Vertical Standing Postures.** Gordon ME, Zajac FE, Khang G, Loan JP, in *Computational Methods in Bioengineering, 1988 ASME Winter Annual Meeting in Chicago*, BED(9):481-492, R.L. Spilker, B.R. Simon (Eds.), New York: The American Society of Mechanical Engineers, 1988.

**Muscle's Action to Produce Joint Angular Acceleration with Application to Standing.** Zajac FE, Gordon ME, in *Proceedings of the XIIth International Congress of Biomechanics*, Los Angeles, CA, Department of Kinesiology: UCLA, Paper 170:1-2, 1989.

**A Planar Model of the Knee Joint to Characterize the Knee Extensor Mechanism.** Yamaguchi GT, Zajac FE, *J Biomech* 22:1-10, 1989.

**Determining Muscle's Force and Action in Multi-Articular Movement.** Zajac FE, Gordon ME, in *Exercise Sport Science Reviews*, 17:187-230, K. Pandolf (Ed.), Baltimore: Williams & Wilkins, 1989.

**Feasibility and Conceptual Design of Functional Neuromuscular Stimulation Systems for the Restoration of Natural Gait to Paraplegics Based on Dynamic Musculoskeletal Models.** Yamaguchi GT, PhD Diss., Stanford University, 1989.

**Sensitivity of Simulated Human Gait to Neuromuscular Control Patterns.** Yamaguchi GT, Zajac FE, in *Proceedings of the XIIth International Congress of Biomechanics*, Los Angeles, CA, Department of Kinesiology: UCLA, Paper 166:1-2, 1989.

## [251] Skeletal Muscle Fiber Recruitment at Submaximal Intensity: Implications for Stimulation Therapy

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Sponsor: VA Rehabilitation Research and Development Service (Project #B342-RA)

**Purpose**—The purpose of this study was to directly measure the distribution of muscle fibers activated at submaximal stimulation levels. Such information has important consequences in therapeutics: for example, the amount and type of muscle fibers recruited during therapy may not be the same as those recruited during volitional movement.

**Methodology**—The rabbit tibialis anterior (TA) muscle and peroneal nerve were isolated. The rabbit leg was immobilized and the distal TA tendon secured to a force transducer. The peroneal nerve was then activated at various currents yielding muscle tensions ranging from 5 percent to 100 percent maximum tension.

**Results**—There was a significant difference between the percentage of each fiber type activated (as measured by glycogen depletion) and the percentage

of each fiber type present in that sampling region ( $p < 0.05$  for all fiber types).

The results of this study provide direct support for the concept that external electrical nerve stimulation recruits muscle fibers in "reverse order" relative to normal muscle activation. Reverse recruitment has significant consequences in the use of functional electrical stimulation (FES) for rehabilitation. For example, when using FES for muscle strengthening, fast fibers may be recruited most often during therapy, and therefore receive the greatest strengthening stimulus. However, during normal movement, these fibers are *rarely* recruited, and therefore, the resultant strengthening may be of no practical use to the patient.

### Publications Resulting from This Research

**Comparison Between Human and Animal Studies of Skeletal Muscle Adaptation to Chronic Electrical Stimulation.** Lieber RL, *Clin Orthop* 233:19-24, 1988.



**Differential Effects of 10 Hz and 50 Hz Stimulation of the Tibialis Anterior on the Ipsilateral, Unstimulated Soleus Muscle.** Lieber RL, Ferro TD, Hargens AR, *Exp Neurol* 100:426-435, 1988.

**Time Course and Cellular Control of Muscle Fiber Type Transformation Following Chronic Stimulation.** Lieber RL, *International Science Institute Atlas of Science: Animal and Plant Sciences*, 1:189-194, 1988.

## **[252] Trial of Chronic Electrical Stimulation in Early Duchenne Muscular Dystrophy**

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**Sponsor:** *The Channel 7 Children's Research Foundation of SA, Inc.*

**Purpose**—The aim of this study is to test the hypothesis that chronic electrical stimulation increases strength and endurance in the early phase of Duchenne muscular dystrophy.

**Progress**—As a pilot project, we are testing a large proximal muscle, the quadriceps femoris, over a period of 16 weeks in 3 boys aged between 6 and 8 years old. Stimulators have been obtained from Neen Pain Management Systems, U.K. A system for measuring strength, consisting of a positioning chair, force transducer, amplifier, display, and plotter, has been assembled. Baseline measurements

have been carried out and active stimulation is under way. One leg will be stimulated for 8 weeks, after which the other leg will be stimulated for an additional 8 weeks.

**Future Plans**—Our results may help define whether chronic electrical stimulation should become part of the therapeutic armamentarium in the management of Duchenne dystrophy by delaying the progressive weakness characteristic of the condition.

### **Publications Resulting from This Research**

None reported.

## **[253] Fatigue of Paralyzed Muscles Activated by Functional Electrical Stimulation in Paraplegics**

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**Sponsor:** *Technion VPR Fund; The Israel Ministry of Defense; Segal Foundation; Montreal Biomedical Research Fund; Archia Micay Biomedical Research Fund*

**Purpose**—The objectives of this project are to study the problem of fatigue of paralyzed muscles of paraplegic patients externally activated by functional electrical stimulation (FES). The problem is divided into three main components: 1) biomechanical expression of fatigue, i.e., studying the patterns of force decay due to sustained stimulation; 2) myoelectric expression of fatigue, by means of measuring the surface electromyogram (EMG) of the fatiguing muscle; and, 3) metabolic expression of fatigue during muscle contraction. Preliminary investigations have led us to the conclusion that the optimal technique for the metabolic studies is

obtained by using the noninvasive P-31 magnetic resonance spectroscopy (MRS) of the stimulated muscle.

**Methodology**—The leg of a paraplegic patient presents a unique system whereby the only active muscles are those stimulated by FES. This is in contrast to the leg of a normal subject, in which several groups of muscles are simultaneously functioning during most activities. Under such conditions, the leg of a paraplegic patient can be analyzed as a determinate system, enabling the calculation of the force output within the stimulated muscle. The



following stages have been achieved: 1) design and construction of the stimulating apparatus (for surface stimulation); 2) design and construction of dynamometers for on-line monitoring of the muscle force output under both isometric and isotonic conditions. Measurement is possible in the lying and sitting positions of the tested patient; 3) design and construction of a dynamometer for monitoring muscle force in the MRS apparatus; and, 4) measurements of force, EMG, and preliminary measurements of MRS.

The MRS studies are being made on a Gyrex 2T magnetic resonance imaging (MRI) instrument, equipped with 31-P MRS facilities.

**Results**—Force decay characteristics under sustained stimulation conditions were obtained of isometric contractions in various knee angles. EMG of the activated muscle was found to correlate well with the force measured, at force levels higher than 20 percent of the maximal contraction force (power curve-fit). The peak-to-peak amplitude of the M-wave obtained was selected to represent the EMG parameters.

P-31 MRI measurements included the high energy compounds, adenosine triphosphate (ATP), and phosphocreatine (PCR). The inorganic phosphate (Pi) level was too low to be detected on this machine. FES induced a pronounced variation in these components: as PCR levels declined, the Pi peak, which was accompanied by a strong signal,

became important, corresponding to sugar phosphates (SP). The intracellular pH could be calculated from the chemical shift between the PCR and Pi peaks. During FES, the force declines to 50 percent of its initial value in the first minute, to 30 percent in the second minute, and to 25 percent in the third. During the recovery phase, the recorded spectra showed a reversal of the situation: PCR level increased, while Pi and SP levels decreased, all approaching the rest levels. This phase took an average of 30 minutes until complete recovery was reached.

**Future Plans**—Our next efforts will be directed toward correlation of the mechanical, myoelectric, and metabolic factors involved in expressing fatigue of FES-activated paralyzed muscles. We hope that the results will enable researchers to express more completely the phenomenon of fatigue, for more effective application of FES.

#### Publications Resulting from This Research

**Fatigue of Quadriceps Muscles Continuously Activated by Functional Electrical Stimulation.** Levy M, Mizrahi J, Susak Z, Solzi P, in *Electrophysiological Kinesiology*, 65-68, W. Wallinga, H.B.K. Boom and J. de Vries (Eds.), Amsterdam: Elsevier Science Publishers, 1988.

**Time-Variation of Quadriceps Muscle Force and Related EMG During Uniform Electrical Stimulation in Paraplegics.** Mizrahi J, Levy M, Steinvil Y, Susak Z, Solzi P, in *Proceedings of the World Congress on Medical Physics and Biomedical Engineering*, San Antonio, TX, 385, 1988.

#### [254] Measurement of Recruitment Properties of Implanted Nerve Cuff and Epimysial Electrodes

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Sponsor: National Institute on Disability and Rehabilitation Research

**Purpose**—Implantable neurostimulators are currently being designed to control functional movements of paralyzed extremities. Specifications must be established to permit fine control of muscle force for all implantable electrodes with which the stimulators are to be used. The purpose of this project was to document recruitment data of two of the most common types of implantable electrodes—wrap-around nerve and epimysial muscle elec-

trodes—and to derive specifications for range and resolution of pulse amplitude and duration for future neurostimulators. Results from a similar study using a cuff electrode manufactured by Avery Laboratories have previously been published.

**Methodology**—The nerve electrode used in the study was a bipolar bidirectional helix electrode fabricated by the Huntington Research Institute, Pasadena,



CA. Two platinum ribbon electrodes, 1 mm in width and separated by 7 mm, were mounted inside two 2 mm diameter helical coils made of silicon rubber. A special tool was used to assist in wrapping the helical coils around the nerve. The epimysial electrode consisted of a 1×2 mm platinum disk fixed to a 1 cm diameter sheet of silicon rubber reinforced with dacron. The ground electrode used with the epimysial electrode was a 9 mm diameter titanium disk coated on one side with silicon rubber.

One electrode of each type was implanted in 7 cats. The nerve electrode was placed on the left posterior tibial nerve, and the epimysial electrode was sewn to the right lateral gastrocnemius muscle. The ground electrode was placed subcutaneously in the right low back/abdominal region. The animals were maintained for up to 24 weeks, and recruitment data were collected from both electrodes every 4 weeks. Recruitment data were obtained by fixing the pulse duration of monophasic constant-current rectangular pulses and varying pulse amplitude over the range between threshold and maximum recruitment. Isometric muscle twitches were used to mini-

mize fatigue, and the peak value of the resulting twitch was recorded along with the corresponding values of pulse amplitude and duration. A software program was written to assist with the data collection.

**Results**—Data collection has been completed and analysis of the data is in progress. The design specifications have been shown to provide fine control of muscle tension using pulse duration modulation for the nerve and epimysial electrodes used in this study.

#### Publications Resulting from This Research

**A Computerized System to Generate Recruitment Data for Neuromuscular Electrodes.** Tu W, McNeal DR, Baker LL, in *Proceedings of the 11th Annual International Conference of IEEE/EMBS*, Seattle, WA, 1989.

**Recruitment Data for Nerve Cuff Electrodes: Implications for Design of Implantable Stimulators.** McNeal DR, Baker LL, Symons J, *IEEE Trans Biomed Eng* 36(3):301-308, 1989.

**Selection of Stimulator Output Specifications Based on Recruitment Characteristics of Implanted Electrodes.** McNeal DR, Baker LL, Tu W, Robben MAM, in *Proceedings of the Osaka International Workshop on FNS*, Osaka, Japan, 1989.

### [255] Characterization of the Flexion-Withdrawal Reflex for Use in Stimulation-Assisted Gait

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**Sponsor:** National Institute on Disability and Rehabilitation Research

**Purpose**—This project lays the ground-work for investigation of closed-loop control methods to regulate the swing-phase of gait of paraplegic individuals walking with the aid of electrical stimulation (ES) to their lower extremity muscles. The leg can be advanced forward by eliciting the flexion-withdrawal reflex using a burst of ES. However, repeated elicitation causes a loss of reflex responsiveness, referred to as “habituation.” To design an appropriate controller, the dependency of the reflex kinematic and habituation characteristics on stimulation parameter values were studied.

**Methodology**—Five paraplegic subjects (T4 to T12) with no motor control stood upright in a special frame supported by a parachute harness and brace on the contralateral leg. The ball of the ipsilateral

foot rested on the ground with the ipsilateral toe aligned even with, or up to, 5 inches behind the contralateral heel. Movement of the ipsilateral hip, knee, and ankle were recorded by electrogoniometers. Data were sampled at 100 Hz triggered by the onset of stimulation.

Rectangular, monophasic pulses of 0 to 300  $\mu$ s duration (PD), 0 to 230 mA amplitude (PA), and 10 to 1000 ms inter-pulse interval (IPI) could be delivered for programmable durations (BD). The cathode (2 cm diameter) was placed over the common peroneal nerve in the vicinity of the popliteal fossa, and the anode (2 cm diameter) was placed over the tibialis anterior muscle.

Stimulus pulses for the habituation studies were delivered with 10 or 50 ms IPI's for 700 ms bursts every 5 seconds. PA and PD values were selected to



generate from 25 to 35 degrees of peak hip flexion due to one burst. For studies of the kinematic dependency on ES parameter values, values for each parameter were varied about nominal ES values of 50 ms IPI, 700 ms BD, with PA/PD values selected to generate 25 to 35 degrees of peak hip flexion.

**Preliminary Results**—The peroneal reflex site was chosen for its reported excitability and its close proximity to potential implant sites in the thigh for implantable stimulators. The cathode location was usually found from 1 cm posterior of the fibular head to the midline of the calf, and from 1 to 6 cm distal to the popliteal crease.

For two subjects, the reflex alone was adequate to advance the leg forward in a step similar to normal leg advancement. For one subject, the reflex generated leg advancement with persistent knee flexion. For the remaining two subjects, the reflex generated hip flexion and adduction that interfered with leg advancement; step length was shortened by persistent knee flexion. To complete leg advancement with these two subjects, ES of the gluteus medius and quadriceps femoris muscles would be necessary.

In the typical reflex movement, the knee flexed 50 ms prior to hip flexion, possibly due to efferent ES of the gastrocnemius muscle. The ankle dorsi-

flexed during swing, then plantarflexed following peak hip flexion.

Changing ES parameter values singly about the nominal set demonstrated that: 1) peak hip angle varied directly with PD; 2) hip angle latency varied inversely with PD for three subjects; 3) peak hip angle varied directly with BD up to 700 ms, after which, BD had no effect; 4) peak hip angle varied inversely with IPI; and, 5) hip angle rise time was not consistently dependent on any one parameter.

Repeating a fixed set of ES bursts every 5 seconds using a 50 ms IPI advanced the leg longer than a 10 ms IPI set for two subjects. With one subject, the leg advanced 100 cycles with no apparent habituation using the 50 ms IPI set, and advanced only 6 cycles using the 10 ms IPI set. For the second subject, the leg advanced 36 cycles and 9 cycles, respectively. For the remaining three subjects, the leg advanced at most 3 cycles using either ES set.

**Future Plans**—Further investigation should include: 1) the influence of contralateral reflex stimulation and background efferent ES on the reflex; 2) the recording of EMG activity of reflex muscles; and, 3) the study of additional subjects to verify findings.

#### **Publications Resulting from This Research**

None reported.

## **[256] Muscle Models: Applications in Electrical Stimulation**

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**Sponsor:** *National Science Foundation*

**Purpose**—The design of high performance functional electrical stimulation (FES) systems requires prior knowledge of the muscle's dynamic model. Models derived from intact humans do not provide information on a single muscle, as is needed for FES applications, while previous work using FES to develop models is useless due to the deployment of unphysiological stimulation (i.e., reverse recruitment, etc.). Therefore, we undertook to investigate the dynamic model of skeletal muscles, using a newly-developed FES system capable of orderly

recruitment of motor units with concurrent firing rate control at different strategies.

**Progress/Results**—A series of studies reveals that the basic model of a skeletal muscle consists of a second order linear system with double poles and a pure time delay. This model applies to many different muscles in the hindlimb of the cat. In nine different skeletal muscles, the pole values ranged from 1.6 Hz to 2.8 Hz, and the time delayed ranged from 9 to 18 ms, accounting for conduction velocity



in the nerve and muscle, neuromuscular transmission, and cross-bridge coupling. The variability in the pole values and time delay were shown to emerge due to compounded effects of fiber type, tendon length, muscle mass, and cross section area.

Variations of the stimulation control strategy did not have a significant effect on the model.

#### **Publications Resulting from This Research**

None reported.

### **[257] Closed-Loop Control of Functional Neuromuscular Stimulation Using Implantable Force Sensors**

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**Sponsor:** *Paralyzed Veterans of America; Medical Research Council of Canada; Muscular Dystrophy Association of Canada*

**Purpose**—Current functional neuromuscular stimulation (FNS) systems for the control of limb movements require careful visual monitoring and do not compensate well for changes in load or joint position. It has been shown that closed-loop control of an FNS system using feedback information from sensors results in a better movement system. However, the clinical implementation of closed-loop control has been hindered by a lack of suitable sensors. The purpose of the current project has been to develop, test, and evaluate a closed-loop control FNS system where skin contact force information is derived from the sensory activity recorded directly from peripheral nerves.

**Progress**—A servo-controlled linear motor was implemented to apply a range of computer-generated mechanical inputs to the footpads of anesthetized cats. A variety of methods of signal analysis has

been used to process and compare the electro-neurogram of the tibial nerve to the force applied to the footpad by the servo-controlled motor.

**Future Plans**—The signal analysis will be extended to include the dependency of the nerve signal on various factors of the force input signal (angle of incidence on footpads, force amplitude, and frequency). The filtered nerve signal will be implemented as feedback for the closed-loop control of FNS of ankle extensor muscles in anesthetized, chronically-implanted cats. It is expected that the electroneurogram/contact force relation will be well-defined for each cat and can be used as a feedback source to regulate contact force in this FNS system.

#### **Publications Resulting from This Research**

None reported.

### **[258] Implementation of a Functional Electrical Stimulation (FES) Walking System for the Incomplete Spinal Cord Injured Patient**

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**Sponsor:** *Scottish Home and Health Department*

**Purpose**—The incomplete spinal cord injured (ISCI) patient presents a unique set of symptoms due to the site of lesion and the degree of sparing. Hence, for the restoration of walking of ISCI patients using surface electrical stimulation (ES), an overall strategy based on the needs of the individual patient, is

needed. The aim was to broaden the category of ISCI patient who might benefit from such a program by basing the application on individual needs.

**Methodology**—The strategy implemented at the University of Strathclyde was: 1) an initial assess-

ment of the patient's needs; 2) a comprehensive rehabilitation program to include standing and walking; and, 3) the implementation of a walking system, with a procedure for evaluation and improvement.

The assessment tests provided information on the strategy to be used for the rehabilitation program (e.g., muscle strengthening and tone reduction), as well as identifying requirements (muscle groups, sequences, stimulation parameters) for the implementation of a gait strategy. The assessment tests were performed prior to the commencement of any use of ES for subject rehabilitation as are the tests for the responses to ES. Once this initial phase was completed, the results were analyzed and the initial problems identified.

The rehabilitation program comprised an exercise regime aimed at: 1) ensuring that the muscle was able to work through the full range; and, 2) increasing the strength and endurance of muscle groups.

Gait strategy was implemented when the subject was able to sit and stand, and to perform eccentric and concentric exercises for 5 minutes while standing.

For gait synthesis in the laboratory, a computer-controlled Strathclyde 8-channel stimulator linked to a microcomputer was used. This system allowed the development of a control algorithm which consisted of a series of changes in stimulation sequences and parameters in response to a switch input by the subject. A system for the evaluation was then implemented and stimulation parameters and timing sequences adjusted until a satisfactory gait was produced.

Parameters of stimulation were altered to: 1) change the sensation produced; 2) reduce extensor tone; and, 3) improve flexion pattern. Timing between channels was changed to allow for: 1) latency of the flexion withdrawal response; 2) adequate knee extension before heel strike; and, 3) a smooth gait pattern.

Video recordings were made in the antero-posterior (AP) and medio-lateral (ML) planes to help decide on the efficacy of a particular strategy and to formulate the next phase of gait synthesis. Based on these results, each patient was provided with a stimulator to suit their individual needs.

Patients' home requirements emphasized exercises and gait. Home visits were arranged for all subjects at 2-week intervals to fit their domestic arrangements.

**Progress**—Evaluation after continuous use by the patient was based on: 1) weightbearing while standing and walking; 2) assessment of the effects on activities of daily living; 3) analysis of ground reaction forces on the feet and crutch; and, 4) mobility assessment in terms of walking speed and stride lengths.

Six patients varying in lesion level from C6 to L1 have undergone this program. The number of channels of stimulation required to produce a satisfactory gait has ranged from 1 to 6. Three months after completion of the program, one patient uses the system in the community, two use it regularly at home, one irregularly at home, and two patients do not use the system at all.

#### **Publications Resulting from This Research**

None reported.



## VIII. Functional Assessment

*For additional information on topics related to this category see the following Progress Reports: [19], [40], [51], [211], [284], [292], [362], [392], [410].*

### [259] Evaluation of a Semiautomatic Method for Quantification of Hand Function Using an Electronic Glove (Dataglove™) Computer System

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A458-RA)

**Purpose**—The purpose of this project is to evaluate a fiber optic glove (Dataglove™) for hand functional assessment.

**Methodology**—Dataglove™ is a lightweight glove that measures flexing of finger joints. The degree of flexion of finger joints is measured by analog optical flex sensors mounted over the dorsum of the finger joints on a stretchable inner glove. The Dataglove™ interface converts the output of each flex sensor into 8-bit digital values and transmits them to the host computer (Macintosh™).

The Dataglove™ was evaluated for potential application to the clinical problem of hand function assessment. It was then compared to standard manual goniometer methods for measuring hand motion and to the electromagnetic (Polhemus™) 3-D tracker. The right index finger proximal interphalangeal joint of a normal volunteer and single axis joint models were used.

A mounting system for the Polhemus tracker was fabricated and attached to a Stack™ splint. The Stack™ splint was applied over the Dataglove™ and used to immobilize the distal interphalangeal joint while the proximal joint was evaluated. To minimize other movement, the hand rested on a foam plastic-and-wood support. The finger, extended fully, was adjusted to the horizontal 0 degree calibration of the Polhemus™ 3-D tracker.

Manual goniometer measurements were made by sighting along the radial side of the index finger and matching the angle of the goniometer to the top surface of the digit at 5-degree intervals for the range of 0-to-90 degrees as displayed by the 3-D tracker. The subject was asked to see the Polhemus™

values displayed, and would tell the examiner (who could not) “OK” when the finger position was at the desired 5-degree incremental value. Then, the manual measurement was made.

**Progress**—Initial accuracy studies of the glove are completed. Present studies are evaluating the repeatability of the glove for simultaneous measurements for multiple joints in normal subjects. Further studies are underway to compare the glove measurements with 3-D radiographic evaluations of a hand within the glove.

**Results**—For manual goniometer methods, there was a  $\pm 5$  degree variability between examiners in the interpretation of the same displayed goniometer settings. There was less variability between examiners in the interpretation of the same displayed goniometer settings. Less variability was seen in the measurements taken at consecutive increments of the range (i.e., 0-to-5 to 10-to-15 degrees) than when readings were made in a discontinuous, random manner. Overall accuracy and repeatability were  $\pm 5$  degrees. Dataglove™ single joint performance data per flex angle demonstrated the resolution to be better than 0.5 degrees for angles  $< 36$  degrees, better than 1.0 degree for angles between 36 and 54 degrees, and 2.5 degrees for angles  $> 54$  degrees.

**Future Plans/Implications**—Studies are planned to study Dataglove™ on clinical subjects, including: evaluations of arthritic hands, traumatically injured hands, and other acquired problems. It is also capable of dynamic 3-D recording of hand motions that could be used for semiautomated tests of hand



function similar to the Jebsen standardized test of hand function. This would provide a method to develop virtual tests of hand function. Future versions of the glove will need to incorporate force

feedback to properly perform virtual tasks.

#### **Publications Resulting from This Research**

None to date.

### **[260] Assessment of the Swallow Reflex in Patients with Dysphagia**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #C443-RA)*

**Purpose**—The purpose of this project is to develop a non-radiographic method by which investigators can study certain aspects of swallowing with a variety of repeated measures designs. Ultimately, the results of this investigation will provide information for determining appropriate rehabilitation techniques and evaluating progress for patients with dysphagia.

Objective I will confirm the use of the electroglottograph (EGG) and an electronic pressure transducer as a valid and reliable method of measuring the time (Tsw) between completion of the oral phase of the swallow (T1) and elevation of the larynx (T2). Objective II will study possible age-dependent differences in T1-T2. Objective III will test the effectiveness of current treatments in three subpopulations of patients. We will evaluate the rate of improvement for T1-T2 across treatment groups and diagnoses.

**Progress**—During the first year, an electromyographic (EMG) study was performed to determine which non-swallowing tasks produce significant levels of activation in the superior pharyngeal constrictor muscle of normal subjects during speech and non-speech tasks. The reflexive tasks of swallowing and gagging resulted in the most EMG activity in normal subjects. The gag produced about 60 percent of the activity produced by a swallow. The hierarchy of EMG activity was well-defined and suggested that there may be a hierarchy of tasks that can be used for treating pharyngeal constrictor weakness in dysphagic patients.

The second year has been devoted to analyzing the EGG signal from a Fourcin laryngograph and collecting normative data. At low frequencies, output from the EGG was found to be the inverse derivative of the changes in neck conductivity; this

was not the case in the speech range, for which the EGG had been designed. The EGG output was representative of four stages of the swallow. The preliminary, or first stage, occurred only during dry swallows and was interpreted to be representative of passive laryngeal movement occurring during tongue elevation and retrusion when attempting to produce additional saliva for initiation of the swallow. The second stage represented displacement of the larynx, the third stage represented that period during which the larynx reaches maximum elevation and anterior displacement, and the fourth stage represented the return of the larynx to its resting position. Although the act of swallowing, referring to passage of a bolus, generally occurred in less than 750 ms, laryngeal movement occurred for as long as 2 seconds.

Also during this year, we began to pay close attention to the high number of patients we saw in the clinic who exhibited vallecular stasis without other indicators of decreased pharyngeal constrictor function, such as pyriform sinus stasis or pharyngeal wall residue. Consequently, we began to pay close attention to the epiglottis.

**Results**—We have viewed over 450 tapes of dysphagic patients and have concluded that vallecular stasis is often a symptom of epiglottic dysfunction with or without pharyngeal constrictor weakness. We have identified 4 types of epiglottic dysfunction: an absence of epiglottic movement; incomplete epiglottis inversion; approximation of the epiglottis to the base of tongue; and, prolonged epiglottic inversion. We are also looking at the incidence of aspiration as a function of type of epiglottic dysfunction and at the relationship of disease category to type of epiglottic dysfunction.



**Future Plans**—Along with meeting the objectives of our research questions, we believe it is important to study the extent to which the neural systems involved in non-reflexive activation of the pharyngeal constrictor muscles are intact in various subpopulations of dysphagic patients. Additionally, we

hope to continue studying the relationship between disease categories and oral/pharyngeal dysfunction during swallowing.

#### **Publications Resulting from This Research**

None reported.

### **[261] Development of an Interactive Arm Ergometer and Computer Graphics System**

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VA Medical Center, Danville, IL 62832

**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A418-DA)*

**Purpose**—The purpose of this study is to assess the efficacy of combining an interactive computer game with arm ergometry exercise to stimulate more aerobically beneficial exercise intensity by VA Medical Center patients. The game scenario involves a hot air balloon race, wherein success and failure are determined by the degree to which the subject maintains his/her prescribed heart rate (i.e., 70 to 80 percent of subject's predicted maximum heart rate) during exercise. To date, the project has focused on the development of the game software and the hardware needed to accommodate the input of the subject's heart rate to the computer. Clinical testing of the device is now underway.

**Methodology**—Thirty VA Medical Center outpatients with no history of cardiovascular disease have volunteered to participate in the study. Because Medical Center clinicians determined that only 15 subjects could be trained at a time without disrupting services to other patients, two separate experiments are being performed to accommodate the training of the 30 subjects. Within both experiments the subject's wheelchair locomotion fitness level is being assessed using a 10-minute wheelchair propul-

sion protocol on a set of wheelchair rollers. Additionally, each subject's upper body fitness is being assessed using a submaximal arm ergometer fitness test. Following completion of these pretests, the subjects are randomly assigned to experimental groups receiving: 1) regular arm-crank training without heart rate feedback; 2) regular arm-crank training with heart rate feedback from a heart watch; or, 3) arm-crank training with heart rate feedback provided by the interactive computer-driven hot air balloon race game.

The subjects will arm-crank 3 days per week for 8 weeks with sessions lasting 30 minutes. At the end of the training period, the wheelchair locomotion test and submaximal arm-crank test will again be performed to determine whether the 3 treatments elicited differential training effects. Differences in exercise quality across the 3 treatments will also be assessed by comparing the degree to which subjects achieve and sustain the prescribed level of training intensity.

#### **Publications Resulting from This Research**

None reported.

## [262] System for Integrating and Reporting of Occupational Therapy Functional Assessment

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**Roger O. Smith, MOT, OTR; Jay Hinkens, BS**

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, University of Wisconsin-Madison, Madison, WI 53705

**Sponsor:** *American Occupational Therapy Foundation*

**Purpose**—For the past 4 years, faculty and staff in several programs at the University of Wisconsin of Wisconsin-Madison—including University Hospitals and Clinics, the School of Allied Health Professions, and the Trace Center—have been working on the development and testing of a functional assessment system. An initial paper form of the System for Integrating and Reporting of Occupational Therapy Functional Assessment (SIR-OTFA) has been through pilot testing in the field to test and validate its reliability.

Because of its complexity, however, the SIR-OTFA remains difficult and time consuming to administer, impeding its acceptance in the field and making the tasks of testing the assessment and promoting its use very difficult.

**Methodology**—It was determined that a properly designed computerized version of the SIR-OTFA would greatly facilitate administration, scoring, and charting of results. This would make testing of the assessment more accurate (by reducing the possibility of calculation errors), and could serve to increase the number of researchers and clinicians interested in and able to evaluate the assessment.

A pilot version of the SIR-OTFA software was to be developed first, in order to test different interface concepts and gauge reactions from potential users. The software would step the user through

the stages of the assessment following the nodes of the decision tree. The program would solicit scores from the user, tabulate and total scores automatically, keep records, and automatically chart results graphically.

**Progress**—A “proof-of-concept” version of the software has been programmed, sufficient to show the SIR-OTFA’s software potential. Versions were demonstrated at the 1989 American Occupational Therapy Association (AOTA) and RESNA conferences. Comments on ease of use and effectiveness were solicited, and those who expressed a strong interest in testing were added to a mailing list to receive information on SIR-OTFA development.

**Results**—The AOTA has agreed to disseminate and market the SIR-OTFA throughout the occupational therapy profession, and to begin a continuing education series aimed at increasing the level of competency of SIR-OTFA users. The Trace Center has stated its willingness to support the AOTA in its efforts. It is anticipated that, after this first year, 500 to 1000 sites will be using the SIR-OTFA as a clinical tool.

### **Publications Resulting from This Research**

None reported.

## [263] Studies on the Mechanism and Management of Pathological Tremor

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**Michael J. Rosen, PhD; Ivan Baiges; Steven Beringhouse; Scott Maxwell; Sheila Egloffstein; Fletcher McDowell; Bruce Volpe; Michael Reding; Mindy Aisen**

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**Sponsor:** *Burke Rehabilitation Center; National Institute on Disability and Rehabilitation Research*

**Purpose**—Three interconnected projects have been initiated which focus on the intention tremors which

may be seen following head injury and as symptoms of multiple sclerosis and other neurological diseases.



These investigations have had both clinical and research goals, but are unified by the use of instrumented sensing of movement and controlled mechanical loading of tremorous limbs. A brief

summary of the central ideas, methods, accomplishments to date, and plans for continued work is presented here for each of the three projects.

### **Experimental Evaluation of a Damped Joystick**

**Purpose**—Assistive technology controlled proportionally via a 2-degree-of-freedom (DOF) joystick—in particular, electric wheelchairs and environmental control systems—is inaccessible to people with disabling tremor. Even with electronic filtering which may be incorporated into such systems, the large amplitude movements which are involuntarily superimposed on the intended motions of these people so degrade the signal-to-noise ratio of their acts that accurate steering or remote manipulation is impossible. In response to this problem, this group has developed and patented a viscously damped joystick

based on a simple chamber of silicone grease through which a drag element moves as the joystick handle is controlled. In the present project, the prototype unit was redesigned and new units built to allow convenient external calibrated adjustment of damping. Video tracking and path-following experiments undertaken with 3 tremor-disabled subjects to date demonstrate dramatic and consistent reduction in tremor during voluntary activity. Experiments continue with a view to confirming the generality of present results and demonstrating improved accuracy during control of actual wheelchairs.

### **Design and Testing of a 3-Degree-of-Freedom Controlled Energy-Absorbing Orthosis**

**Purpose**—To meet the need of tremor-disabled individuals to perform many activities of daily living independently and accurately, an orthosis has been designed, built, and tested, which has approximately the same geometry as a standard “mobile arm support.” In each of the 3-DOF it affords the user, movements are resisted in a controlled manner by a magnetic particle brake, computer-controlled to behave as a variable-viscosity damper. A linkage

transmits torque to the device’s “elbow” from a brake fixed on the chair frame so that neither of the two most proximal brakes are “carried” by the moving orthosis. Mechanical stiffness at the end-point is sufficient to allow only 0.2-inch deflection under a 50 lbf vertical load. Abstract and functional tests with 6 subjects demonstrate sufficient reduction of tremor, that in some cases, independent function, lost years earlier, is returned.

### **Fabrication and Testing of the MED Arm, a 6-Degree-of-Freedom Manipulandum**

**Purpose**—A 6-DOF back-drivable manipulator, whose actuators are magnetic particle brakes, was developed by the Harvard-MIT Rehabilitation Engineering Center. It is meant as a research tool to study whole-arm tremor and as a prototype energy-dissipating orthosis for tremor-disabled people. Funding from Burke Rehabilitation Center, White Plains, NY, has allowed the detailed design and the control principles developed by Scott Maxwell to be implemented. The manipulandum detailed design is

complete and the prototype is currently being built. The final design is a 6R serial link device. The three distal DOF are arranged in the form of a novel gimbal configuration. Two of the proximal DOF are mechanically coupled through a 4-bar mechanism providing, in effect, 2 rotations and a near-prismatic joint. This design is driven largely by our goal of building a system with a diagonal Jacobian matrix to provide end-point force-velocity co-linearity. The manipulandum will apply its 6-DOF load at a single

point of attachment on the hand, wrist, or distal forearm. Fabrication is underway at this writing and experiments with patients at Burke are planned for the spring of 1990.

#### **Publications Resulting from This Research**

**Viscously Damped Joystick for Proportional Control by Tremor Patients.** Beringhouse S, SM Thesis, Department of Mechanical Engineering, Massachusetts Institute of Technology, 1988.

**Development and Evaluation of an Upper-Extremity Orthosis for Tremor Suppression.** Baiges I, SM Thesis, Department of Mechanical Engineering, Massachusetts Institute of Technology, 1989.

**Development of a Whole-Arm Orthosis for Tremor Suppression.** Baiges I, Rosen MJ, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 290-291, 1989.

**A Virtual Environment System for the Study of Human Arm Tremor.** Adelstein BD, PhD Thesis, Department of Mechanical Engineering, Massachusetts Institute of Technology, 1989.

### **[264] Validation of an Instrument to Measure Gross Motor Performance for Evaluation of Treatment Outcome in Cerebral Palsy**

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**Sponsor:** *National Health Research and Development Programme*

**Purpose**—The purpose of this study was: to determine the validity of the Gross Motor Performance Measure (GMPM) in children with cerebral palsy from 1 to 19 years of age; to determine the inter-rater and intra-rater reliability of the GMPM; and to test the responsiveness of the GMPM in detecting clinically important change.

**Methodology**—A multi-center group of investigators is directing the study. Therapists from three centers will assess cerebral-palsied, head-injured, and normal children with Gross Motor Function Measure (GMFM). Subsamples of children will participate in reliability studies and a blinded videotape evaluation of change. Parents and therapists will complete questionnaires regarding change in the child's per-

formance for comparison to change in the GMPM scores. Data analysis will include correlation calculation, and specific hypothesis testing. The GMPM instrument under study was developed in a previous project. Validation of the GMPM is the final phase in the development of an instrument which will be used in future studies of outcome of treatment in cerebral palsy.

**Progress**—The first months of this project have been spent in the development of procedures, forms, and training material prior to enrollment of subjects in the study.

#### **Publications Resulting from This Research**

None reported.

### **[265] Investigation of the Validity, Reliability and Sensitivity of a Technique to Monitor Spasticity in Humans**

**Karen L. Harburn, MD**

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**Sponsor:** *National Health Research and Development Programme*

**Purpose**—The level of spasticity exhibited by stroke patients is an important variable to consider in their rehabilitation, since it is not known whether or not this level is related to functional outcome of treatment. However, no measurement system to date has been able to differentiate, with fine resolution,

the amount of spasticity following a stroke. A pilot study will be conducted to: 1) investigate the reliability of a reflex excitability measurement system; 2) investigate the validity of a reflex excitability measurement technique (REMT) to measure spasticity in the human neuromuscular system; and,



3) assess the sensitivity of the technique, if it proves feasible, both in differentiating stroke severity and in differentiating spasticity level.

The final goal, in this direction of research, is the clinical application of the spasticity monitoring technique. Should the REMT prove to be valid, reliable, and very sensitive, it will be used to measure spasticity level throughout a randomized clinical trial study of two stroke treatment ap-

proaches. This study will be designed mainly to ask the question of whether or not the level of spasticity is related to the functional status of stroke patients. A secondary goal is to judge the efficacy and cost-effectiveness of the two treatment approaches.

#### **Publications Resulting from This Research**

None reported.

### **[266] Functional and Clinical Evaluation of the Short-Term and Long-Term Effect of an Anteriorly-Tipped Seat in Children with Cerebral Palsy**

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Rehabilitation Engineering and Research Departments, Toronto, Ontario M4G 1R8 Canada

**Sponsor:** *National Health Research and Development Programme*

**Purpose**—The goals of this study are to monitor and record the short-term and long-term effects of a 10-degree forward-inclined classroom chair on the respiratory patterns (using respiratory inductance plethysmography), and posture (using 3D tracking of C7), of children with cerebral palsy.

**Methodology/Results**—Programming has been completed for the upper-limb reaction-time tests. This programming was tried with five cerebral palsy children but was found to be unsatisfactory for noting reaction time. The program will record reaction time, but the problem lies with the cognitive ability of the children. The children understand the task, but seem to be fascinated with being sure the signal light is truly on, or they double check to be sure that they really heard the start signal. In

addition to these hesitations, the children often hover over the switch to be sure that they hit it squarely in the center. Although they were encouraged to be as fast as they could and not worry about where they hit the switch, these problems remained, and made the monitoring of reaction-time very unreliable. Consequently, the Omni Track System, developed in a previous research study to monitor postural sway, was adapted to attempt to track upper-limb movement patterns which are now being monitored for the study.

The results of this study are viewed subject-by-subject, but no overall analysis has been done.

#### **Publications Resulting from This Research**

None reported.

### **[267] Pattern Recognition System for 16-Channel Ambulatory Electroencephalograms in Children**

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**Sponsor:** *National Health Research and Development Programme*

**Purpose**—The present work is an extension of two consecutive projects funded by Health and Welfare Canada, titled “Database from Ambulatory (14-Channel) Cassette Electroencephalograms” and

“Pattern Recognition System for Ambulatory (4-Channel) Cassette Electroencephalograms.” The first project established a computer database of ambulatory electroencephalogram (EEG) signals

from 4-channel ambulatory EEG recordings. The second developed pattern recognition algorithms for 4-channel ambulatory EEG recordings.

**Progress**—The software for the 4-channel “Automated Rule-Based Graded Analysis” has been verified and debugged. Large portions had to be rewritten, and more features added, so that it could be applied to 16 channels.

**Future Plans**—The researchers will begin to record ambulatory EEGs on children and will begin to

develop the program for analyzing 16 channels of EEG information.

The objective of the present research proposal is to develop a pattern recognition system for 16-channel cassette ambulatory EEGs capable of analyzing paroxysmal (epileptiform) activity, artifact, and background, using the methodology developed for 4-channel ambulatory cassette EEGs.

#### **Publications Resulting from This Research**

None reported.

### **[268] Analysis of Cognitive Tasks in Computer Operation**

**Cynthia J. Cress, MS; Gregg C. Vanderheiden, PhD; Jon Miller, PhD**

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, University of Wisconsin-Madison, Madison, WI 53705

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—In order to understand the difficulties individuals with cognitive impairments have in operating computers, researchers must be able to analyze the various task components involved in computer operation. Such an analysis would serve two chief purposes. It would show where additional research on cognitive factors in computer use is most needed and, it would help researchers to determine, for individuals with a particular type of cognitive impairment, at what point the ability to use the computer “breaks down.” In other words, it will distinguish the weak spot (or spots) in the interface for persons with that particular type of impairment.

**Methodology**—The analysis of tasks is to be carried out in two steps: 1) a search of the current human factors literature on computer operation is to be performed, and from this a framework for analysis and modeling of tasks in computer operation is to be assembled; and, 2) this model is to be adapted to reflect the cognitive loads potentially implied in the tasks.

**Progress**—The initial version of the task analysis scheme developed from a human factors theory has been assembled. Current work involves integrating cognitive factors into each component. The frame-

work developed will serve as input to design guideline documents being developed with regard to computers and consumer electronic products.

**Results**—The modified model will then be written up as a working paper. This paper will not be intended as a definitive theory, but rather will be used as a basis for further research, and will be modified and reissued as appropriate. The paper will be disseminated through the Trace Center Reprint Service and through conference presentations when possible.

**Future Plans/Implications**—The theoretical portion of this activity (development of task analysis scheme) will continue with revisions to the working paper. Experiments testing the appropriateness of the scheme for modeling cognitive aspects of computer use will be designed and implemented in the future. The application aspects of the task analysis (experimental testing of behaviors where performance “breaks down”) are to be developed in conjunction with other Trace Center research.

#### **Publications Resulting from This Research**

None reported.



## [269] Quantitative Assessment of Working Memory Span of Individuals Using Computer Input Devices

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**Sponsor:** *National Institute on Disability and Rehabilitation Research; Cerebral Palsy Research Foundation of Kansas; Wichita State University*

**Purpose**—The objective of this project is to investigate effects of computer input devices on the user's working memory span. Character input rates, input efficiency, subjective evaluations, and learning rates are simultaneously estimated. The results should indicate if the system used to input information into a computer significantly affects the mental capacity for performing meaningful mental work. The effectiveness of using subjective impressions of ease of use and/or input rate as criteria for device selection will be evaluated.

**Methodology**—The working memory span measurement is based on the dual task of remembering numbers while typing words. The computer input devices include an AT keyboard, a two-degree-of-freedom keyboard, serial mouse, and an optical pointer.

**Progress**—At this stage of the research, the methodology has been refined and software developed to simultaneously evaluate working memory capacity and rate of information input for a variety of computer input systems. A pilot study has been conducted and the evaluation software modified.

**Future Plans**—The baseline data collection for individuals without disabilities has begun. This data will be used as a comparison to the data collected from the individuals tested with disabilities. Data collection for those individuals will begin within the next three months.

### **Publications Resulting from This Research**

None reported.

## [270] A Method for Evaluating Head-Controlled Computer Input Devices for Disabled Persons Using Fitts' Law

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Although computer input pointing devices and graphics-based operating systems utilizing a mouse and iconic images can make computers easier to learn and more efficient for fully able persons, these same advancements can hamper computer accessibility for individuals with movement impairments. Since these devices require a certain degree of motor control, upper extremity weakness and reduced manual dexterity can diminish a disabled person's capability for using these interfaces and associated software. Alternative mouse devices, such as head-controlled pointers and locators are now becoming commercially available and are intended to help mildly-to-moderately impaired individuals.

Before alternative computer input devices can be selected and evaluated for persons with motor

impairments, it is necessary to have an objective measure of performance. To determine which strategy is most appropriate for a specific individual with special capabilities, it is necessary to have a quantitative metric for comparing performance using these devices. Furthermore, determining the optimum settings for a particular individual requires an objective measure that is reliable and should also have predictive properties. The objective of this investigation was to determine if a Fitts' Law discrete target acquisition task can be used for evaluating alternative computer input interfaces, including head-controlled computer input devices for people with upper extremity movement disabilities.



**Methodology**—Two experiments were performed. The first experiment included 10 normal subjects using both a conventional mouse and an ultrasonic head-controlled pointer. The study tested the hypothesis that a person can perform at the same level when using a head pointing input device as when using a conventional mouse. The second experiment considered a subject having a moderate severity level of cerebral palsy in order to demonstrate the potential of this method using a person with a movement disability. The study investigated the ability for this method to detect performance differences for a motor-impaired subject using a head-controlled input device, both with and without a thoracic support appliance for stabilizing trunk posture.

A discrete movement target acquisition task was developed using computer-input pointing devices and based on Fitts' Law. The task consisted of moving a cursor from the center of a computer display screen to a target located at radial distances of 24.4 mm and 110.9 mm in eight directions. The targets were 2.7 mm, 8.1 mm, and 24.2 mm in diameter. Performance measures included movement time, cursor path distance, and root-mean-square cursor displacement.

**Results**—Average movement time was 306 ms greater (63 percent) using the head-controlled pointer than when using the mouse. The effect of direction on movement time using the mouse was relatively small compared to the head-controlled pointer, which was lowest at 90 degrees and 270 degrees, corresponding to head extension and head flexion, respectively. Average path distance and root-mean-square displacement was lowest at off-diagonal direction (0 degrees, 90 degrees, 180 degrees, and 270 degrees). Fitts' Law described movement time behavior for both the mouse and head-controlled pointing device.

Differences were measured between a subject having cerebral palsy and normal subjects using the head-controlled pointer. Marked improvements in performance were observed after providing lateral trunk support for the disabled subject. This demonstrated the task useful as an evaluative instrument for selection and comparison of alternative pointing devices for movement-impaired individuals, and also for evaluating modifications in the workplace for individuals with movement disabilities.

#### **Publications Resulting from This Research**

None reported.

### **[271] Multi-Degree-of-Freedom Manipulandum for Characterization of Motor Function and Optimization of Assistive Technology**

**Michael J. Rosen, PhD; Scott Maxwell**

Newman Laboratory for Biomechanics and Human Rehabilitation, Mechanical Engineering Department, Massachusetts Institute of Technology, Cambridge, MA 02139

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The purpose of this project is to develop a 6-degree-of-freedom (DOF) modulated energy dissipating (MED) manipulator for assessment of the effects of energy-absorbing loads on upper extremity pathological tremor. This system will serve as a very general prototype clinical tool for measurement and differential diagnosis of movement disorders, and as a means of simulating, with experimental subjects and individual patients, the characteristics of practical tremor-suppression orthoses with up to 6-DOF.

**Progress**—The choice of actively controlled energy-absorbing actuators (controlled brakes) was driven

primarily by considerations of safety; an active robot with 6-DOF poses a considerable hazard when used intentionally in intimate contact with a human.

Theoretical development of MED manipulators demonstrates that a MED manipulator with 6-DOF end-point space, 6 joints, and 6 actuators will be end-point force-velocity co-linear if, and only if, the actuator movements map to an orthogonal set of end-point directions (e.g., the Jacobian between actuator space and end-point space is diagonal). A manipulator with this property will move in the direction that it is pushed. This can be achieved by mechanical geometry or by energetic coupling of



actuator outputs. A more general theory describes the conditions under which the angle between end-point force and velocity can be controlled arbitrarily, up to 90 degrees. These results have been central in the design of the manipulator. Further analysis indicates theoretical limitations to MED manipulators. The limitations are a function of the passive inertia and compliance of the manipulator (both should be small).

The manipulandum detailed design is complete and the prototype is currently being built. The final design is a 6R serial link device. The 3 distal DOF are arranged in the form of a novel gimbal configuration. Two of the proximal DOF are mechanically coupled through a 4-bar mechanism providing, in effect, two rotations and a near-prismatic joint. This design is driven largely by our goal of building a system with a diagonal Jacobian matrix to provide end-point force-velocity co-linearity. The manipulandum will apply its 6-DOF load at a single point of attachment on the hand, wrist, or distal forearm.

The physical limits of the viscous damping algorithm are a function of the combined compli-

ance of the couplers and human soft tissue in shear and compression. The importance of a very stiff coupling between the human bone and manipulator end-point motivates design of very stiff limb-couplers (the name given to the human limb attachment device). The test jig described in the last progress report was used to measure the stiffness of limb couplers on 3 male arms. Initial results of the experiments gave information on which directions needed to be made stiffer, and the limb coupler design was updated accordingly.

**Future Plans**—In the next year, 3 subjects will be completely tested with viscous damping. The subjects will perform objective 2-DOF pursuit target tracking tasks and more function-like tasks abstracted from activities of daily living. The quantitative data will be analyzed for tremor reduction, as well as purposeful movement degradation, using the algorithm developed earlier in this project.

#### **Publications Resulting from This Research**

None reported.

### **[272] Back Assessment of Athletes from Varsity and Freshman Crew Teams**

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**Sponsor:** *NeuroMuscular Research Center*

**Purpose**—This project was initiated to supplement a similar study of the myoelectric (ME) assessment of back muscles in control subjects and patients with chronic back pain. The preliminary findings from that study indicate that asymmetries in muscle endurance capacity and activation were present in many subjects: there were some with and some without a history of back pain. Since these findings suggest an association among muscle imbalances, muscle conditioning, and the presence or absence of chronic back pain, we conducted a supplementary study to clarify this relationship.

**Progress**—We targeted our study to accomplished oarsmen because they have a high level of back

muscle conditioning and, as a group, they have a high incidence of lower back pain. To address the issue of muscle asymmetries, we tested only “sweep” oarsmen because they can be further classified as port or starboard rowers. Twenty-four men from the Boston University varsity crew team participated in the study and have completed the first phase of testing. This series of tests was conducted in the same back restraining device previously described for patients and control subjects. The protocol was abridged to include a maximal voluntary contraction, a variable force contraction, a sustained contraction at 80 percent maximal voluntary contraction, and periodic short-duration contractions to monitor muscle recovery from fatigue.

**Results**—Results from this study demonstrated that low back pain and asymmetrical muscle development in rowers can be assessed on the basis of ME signal spectral analysis.

These results prompted us to begin a similar prospective study on novice rowers from the freshman crew team of Boston University. We have completed the preliminary phase of testing. Addi-

tional repeat tests are planned until the rowers complete their varsity year. It is hoped that our data and analyses will be of use to the individual athletes and their coach as an objective measure for designing and reassessing training procedures.

**Publications Resulting from This Research**

None reported.

### **[273] Back Assessment and Other Muscle Function in Patients with Fibromyalgia**

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**S.H. Roy; R.W. Simms; D. Goldenberg; M. Emley; L. Brody; C.J. DeLuca**

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*Sponsor: NeuroMuscular Research Center; National Institutes of Health*

**Purpose**—Fibromyalgia, also called fibrositis, is increasingly recognized as one of the most common causes of chronic musculoskeletal pain and fatigue. It is classified within the spectrum of generalized nonarticular rheumatism and affects between 3 and 6 million Americans. The most compelling pathophysiologic evidence for objective abnormalities in fibromyalgia has come from recent studies of muscle histology and physiology. These results, although not conclusive, have prompted rheumatologists at the Arthritis Center of University Hospital to study the muscular component of fibromyalgia via objective fatigue measures developed in our laboratory. This interest on the part of our colleagues at University Hospital follows a number of years of clinical research to help delineate fibromyalgia from other similar disorders.

muscle function in the lower-back muscles and muscles of the lower limb. The Back Analysis System is being used to identify abnormal patterns of fatigue during sustained isometric contractions and during recovery. Limb muscles are being tested using a multi-electrode array to measure conduction velocity and changes in spectral parameters of the electromyogram (EMG) that provide an index of fatigue.

**Future Plans**—Patients will also undergo an abbreviated clinical evaluation of muscle tender points and a pain questionnaire. These assessments will be correlated with the EMG results to determine if the musculoskeletal symptoms of fibromyalgia are associated with myoelectric manifestations of muscle fatigue.

**Methodology**—A pilot study is underway in which patients with fibromyalgia are being tested for

**Publications Resulting from This Research**

None reported.

### **[274] Microcomputer-Based Aids for Clinical Measurement: Omni-Track**

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*Sponsor: None listed*

**Purpose**—A three-dimensional measurement and tracking software system, Omni-Track, has been

developed for monitoring and recording movement in three dimensions.



**Methodology**—Omni-Track runs on an IBM XT/AT or compatible with an 8087 or 80287 math coprocessor and EGA video adapter. Data is acquired through a Data Translations DT-2801-A data acquisition card. The system calculates the X, Y, and Z positions based on the voltage measurements from three potentiometers. Omni-Track has seven active modules designed to calibrate the hardware system, adjust to the user, run tests, and view data results.

(1) *Calibrate* runs three tests to determine the actual criteria level during the endurance test. Each calibration test collects position information over a 10-second duration. The object of the test is to have the subject sit as high and as stable as possible for the testing period. This is repeated for each test. At the completion of the three tests, the system visually presents the data. The tester looks for consistent and repeatable measures while viewing the data.

(2) *Endurance* allows continuous monitoring of a subject's position over a preset period of time. The criteria for completion are based on the minimum Z position as determined from the average of the three calibration tests. The test may terminate if the subject's Z position exceeds the criteria for the duration of the test. When running, the test displays the time-out criteria for the test, the time taken during the test, and the actual Z position. The subject must maintain the Z position above a graphic red zone. Falling into this area terminates the test and collected data are saved to disk.

(3) *Quiet Monitoring* is a test structured to the same rules as the endurance test, except feedback of

the Z or height position is not provided. Thus, the subject may fall below the test criteria without terminating the test. This test terminates at a preset time-out period. When running, the test indicates the time-out criteria for the test and the time taken during the test.

(4) *Subject Identification* is a data entry system that records the subject's name, the session or test number being run, the seat angle, and the preset time-out.

(5) *Review Data* permits the user to view the data collected from recorded tests. The data directory is displayed and up to seven records may be viewed or printed.

(6) *Hardware Calibration* is used when the system is first installed, and after any adjustments have been made to the hardware of the system. This includes tracking arm adjustments, potentiometer adjustments, and software modifications.

(7) *Distance* allows measurement of the distance of objects. It reports the X, Y, and Z measurements as well as the absolute distance change.

**Future Plans/Implications**—Omni-Track is currently being used to evaluate the effects of seat angle on posture and sway. Other potential applications of this technology include gestural input to computers and the objective assessment of upper-limb movement.

#### **Publications Resulting from This Research**

None reported.

## **[275] Objective Functional Assessment and Rehabilitation of Low Back Disability**

**Gordon Waddell; Mary Newton**

West of Scotland Back Pain Research Unit, Orthopaedic Department, Western Infirmary, Glasgow G11 6NT Scotland; Gartnavel General Hospital, Glasgow, Scotland

**Sponsor:** *Scottish Home and Health Department; The Mactaggart Trust*

**Purpose**—Our purpose is to develop and analyze a model of low back disability which relates physical deconditioning to psychological distress and illness behavior, and test that model in the clinical reconditioning and rehabilitation of patients with low back disability.

**Methodology**—The first phase is devoted to the theoretical understanding of low back disability. Reproducibility studies will be carried out on 25 patients with chronic low back pain, looking particularly at possible learning effects. Normal data will be obtained on 70 subjects. Objective functional

assessment using isokinetic data will then be correlated with objective clinical characteristics, cardiovascular fitness, psychological distress and illness behavior, visual analogue pain scale cognitive factors, and coping strategies and disability in the activities of daily living for 120 patients with chronic low back pain of more than 3 months' duration.

Particular emphasis will be placed on the relationship between pain, cognitive factors, and disability, and how these change with time. It is hypothesized that physical deconditioning, as shown by the isokinetic data, will correlate with cardiovascular fitness and clinical measures of objective physical impairment, but that the isokinetic data will explain a larger proportion of the variance of pain and disability. It will also show that isokinetic measures and physical deconditioning will also correlate with psychological distress and illness behavior: that disability will depend more on cognitive factors than on pain or physical impairment. This analysis will be used to construct a mathematical model of low back disability.

A controlled study of the clinical value of

physical reconditioning, using the Cybex back system versus standard physiotherapy, will be carried out on 214 patients aged 20 to 55 years with low back pain, with or without referred thigh pain. The treatment group will have a 3-week course of intensive rehabilitation on the Cybex back system. The control group will have standard strengthening and mobilizing exercises. Isokinetic measurements in both groups will be carried out initially, after completing the 3-week treatment, and a 6-month follow-up. Self-report assessment of the effects of treatment on pain, disability in activities of daily living, and return to work will be carried out at 3 weeks, and at 6 months. An independent clinical assessment will be carried out at 6 months, with a single-blind assessment of the final outcome.

**Progress**—The project commenced January 1, 1989. Initial setup and pilot studies are complete. Reliability and normal studies are currently under way.

#### **Publications Resulting from This Research**

None reported.

### **[276] Movement Training and Assessment Systems Using Microcomputers**

**D.J. Wyper; A.F. Newell; H. Gordon; L.M. McKenzie**

Departments of Clinical Physics and Occupational Therapy, Institute of Neurological Sciences, Southern General Hospital, Glasgow, G51 4TF Scotland; Department of Microelectronics, University of Dundee, Dundee, DD1 4HN Scotland; Tayside Health Board, Vernonholme, Dundee, DD1 9NL Scotland

**Sponsor:** *Scottish Home and Health Department*

**Purpose**—The purpose of this study was to design equipment for hand, wrist, elbow, and shoulder exercising.

**Methodology/Results**—The equipment designed is an apparatus based on a rotary dashpot with a resistor potentiometer linking movement information to the microcomputer. The computer is used to provide purposeful activity, usually in the form of games. In addition, the computer can be used as a recording device for logging performance and to compute the amount of work done during the

various activities. Since a dashpot is employed as the resistor part of the rotational device, the resistance to movement increases with speed of movement, and slow movements can be accomplished with ease. This provides a great deal of flexibility for the therapist when planning exercise schedules.

A preliminary clinical evaluation of the instrument has been completed in specialist rehabilitation centers throughout Scotland.

**Future Plans/Implications**—Therapists have expressed a great deal of enthusiasm for the device and



the trials have shown that it has a place in a therapeutic regimen. It is anticipated that a licensing agreement to market the device will be signed with a rehabilitation company in the near future.

### Publications Resulting from This Research

**Computer Linked Apparatus for Upper Limb Therapy: A New System of Resistor Exercise.** Ward E, Beattie A, Wyper D, *Clin Phys Physiol Meas* (in press).

## [277] A System for Digitizing Body Surface Topography

**Max Donath, PhD; Ted Morris, MS**

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**Sponsor:** *University of Minnesota Productivity Center and CIM Consortium*

**Purpose**—Measurement of the surface topography is needed in order to facilitate the custom fitting of orthoses, prostheses, and footwear. This requires the characterization of the three dimensional (3-D) surface of the human body and of the device itself. Computerized measurement systems would allow one to take advantage of CAD/CAM techniques in order to reduce the cost of customized manufacture, and would allow one to develop appropriate 3-D anthropometric databases for improving present assistive device designs. Our objective is to design, build, and evaluate a hand-held 3-D digitizing “wand” prototype.

**Methodology**—A 3-D digitizer which can accurately provide position and orientation information of points on the surface of a body can be developed by taking advantage of 6-degree-of-freedom motion measurement systems which track the XYZ coordinates of multiple targets. Such a system would track the position and orientation of a hand-held digitizing wand coordinate system by tracking an array of target points which are rigidly affixed to the wand. Given the distance to the tip of the wand, the location of a point on an object’s surface in “contact” with the tip can be determined. The system that we use, MnSCAN, can simultaneously track the XYZ locations of multiple photodetector target points at 480 Hz.

**Progress**—From simulations, we found that relatively small manufacturing tolerance errors of the target point lattice can greatly affect the computed position and orientation—even if the motion tracking system is perfectly calibrated and is relatively noise free. As such, we designed a wand prototype

based on a planar target array topology and built a unit to be within the tolerance specifications of the target point photodetectors themselves ( $\pm 0.002$  inches). The wand prototype fabricated currently uses a hard tip for contact with the points on the surface to be digitized. A variety of alternative digitizing tips can be used, based on either contact or non-contact type range sensors. Contact tips can incorporate load cells or linear displacement sensors to ensure that a measurement is performed while applying minimal but constant and repeatable contact forces. We developed the necessary computational algorithms and a graphic interface for real-time viewing (presently 5 Hz) of the digitizing environment and of the position and orientation of the wand tip on a computer screen. This 5 Hz limitation is a result of our desire to implement the device using relatively inexpensive hardware (an Apple Macintosh computer with a serial port to the MnSCAN data acquisition system). Two surface algorithms which enable one to automatically create surface polygons from surface point data were completed and successfully tested.

**Results**—It was found that the repeatability of locating any point in space as determined by the wand is a function of: 1) the distance of the tip from the wand coordinate system origin; 2) the topology of the array of targets attached to the wand; and, 3) the noise in the targets. The first two are a function of the design of the wand itself, while the third is strictly a characteristic of the motion-tracking system. As such, significant improvements in the MnSCAN prototype were made by developing a new method for removing the signal noise in the targets without affecting the system bandwidth. Experi-



ments shows that this method reduced the noise at the 95 percent level of confidence to within the measurement resolution of the system.

**Future Plans**—A new calibration method is now being developed. When complete, the system will be

recalibrated and tested for accuracy and repeatability.

#### **Publications Resulting from This Research**

None reported.

### **[278] Error Analysis of 6-Degree-of-Freedom Motion Tracking Systems**

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**Max Donath, PhD; Ted Morris, MS**

Human Motion Laboratory, Department of Mechanical Engineering, University of Minnesota, Minneapolis, MN 55455

**Sponsor:** *University of Minnesota Productivity Center and CIM Consortium*

**Purpose**—Many clinicians use joint motion data for evaluating treatment modalities (prosthetic devices, joint bracing, surgical interventions, therapy, etc.), for diagnosis. Point target sensing has been investigated and used extensively to track the motion of human anatomical joints in order to allow clinicians to objectively assess the characteristics of joint motion associated with human activities—for example, walking. A common approach to tracking anatomical joint motion consists of tracking the XYZ locations of multiple point targets which are attached to the moving limb segments and then computing the three position and three orientation angles between adjoining segments. Our objective is to quantitatively determine, evaluate, and understand the errors associated with the measurement of 6-degrees-of-freedom (DOF) of relative body motion based on such systems.

**Methodology**—There are several phenomena associated with such measurement systems which contribute errors to the resulting computed 6-DOF or joint motion. We have been investigating the various phenomena which affect the measurement of the relative motion between the adjacent segments. The characteristics of many of these phenomena, common to most 3-D motion tracking systems, were first determined by experimentation using one such system (MnSCAN) in our laboratory. These and additional artifacts were then modeled in a computer simulation to quantitatively study their effects on determining this motion. The analysis of the modeled data uses statistics which lead to geometric

interpretations that can be readily visualized, thus resolving ambiguities in interpreting the rigid body motion errors which expressed using any of a variety of 3-D relative body motion coordinate systems. A calibrated mechanical 3-DOF joint with known kinematics and high resolution was used to experimentally verify some of the relationships for orientation angles developed in the computer simulations.

**Results**—Six sources of error which affect the integrity of the position-orientation estimates were investigated. Errors can be associated with: 1) calibration methods which may lead to target point location measurement offsets; 2) noise in the acquired target location data; 3) perceived target array deformation due to tolerance errors in the relative location of targets, and/or dynamic motion errors caused by tracking moving targets when the system bandwidth is constrained; 4) the type of algorithm used for computation; 5) target array topology (i.e., how the targets are geometrically distributed with respect to each other); and, 6) soft tissue displacement. Our study focused on the first five of these. Based on the simulations, several relationships were identified which predict how each of these phenomena influence the predicted measurement of relative motion between bodies. These suggest where emphasis should be placed in order to minimize the error in measuring the 6-DOF of a joint. The methodology and the conclusions can be applied to any motion measurement system which is based on tracking targets. A calibrated mechanical 3-DOF joint with known kinematics and high resolution was used to



verify some of the orientation angle results developed in the computer simulations. Based on the results derived thus far, more accurate systems are under development for the *in vivo* measurement of all the motions of and about the instantaneous axis of rotation within any number of joints.

## **[279] Computer-Based System for Clinical Assessment of Tremor C-SCAT**

**Michael J. Rosen, PhD; Jorge Romero, MD; Robert Young, MD; Alan Wiegner; Diane Brongo; Theresa Loney**  
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Massachusetts Institute of Technology, Cambridge, MA 02139; Neurology Department, Brockton VA Medical Center,  
Brockton, MA 02401; Neurology Department, West Roxbury VA Medical Center, West Roxbury, MA 02132

**Sponsor:** *VA Rehabilitation Research and Development Service*

**Purpose/Methodology**—Using standard methods, it is difficult to distinguish among tremor types and prescribe drug treatments with a high probability of success. The proposed C-SCAT (Computer-Based System for Clinical Assessment of Tremor) is based on the hypothesis that the variation of tremor under specific mechanical loads will depend on the mechanism causing the tremor and serve to uniquely identify it. The system will employ a PC, a motor, and fixturing devices to create a simulated environment for the tremorous limb in 1-degree-of-freedom. In use, the patient will be required to perform various voluntary movements during the application of simulated mechanical loads.

**Future Plans/Implications**—Data from trials with experimental subjects in follow-up studies to this project will be stored and analyzed to provide indices such as tremor power, peak frequencies, signal-to-noise ratio, etc., as a function of load. This load response will then be correlated with each

### **Publications Resulting from This Research**

**Error Analysis of 6-DOF Rigid Body Motion Tracking Systems.** Morris T, Donath M, in *1988 Advances in Bioengineering*, G.R. Miller (Ed.), BED:8, ASME, NY, 1988.

**The Minnesota Scanner: A Prototype Sensor for Three Dimensional Tracking of Moving Body Segments.** Sorensen BR, Donath M, Yang GB, Starr RC, *IEEE Trans Robot Automat* 5(4):499-509, 1989.

subject's history of successful and unsuccessful drug treatments. This will generate a database demonstrating (it is hypothesized) the creditability of drug response from the tremor "signature" measured with C-SCAT. Preliminary studies toward this experimental goal may be accomplished in the present project. In addition, alternative physician interface designs will be compared via tests with collaborating neurologists. Conceptual design decisions have already been made and work on technical design is underway. We expect the prototype system to be functioning by the end of March 1990.

C-SCAT is a collaborative project of the Newman Lab for Biomechanics and Human Rehabilitation in the Department of Mechanical Engineering at MIT and the VA Medical Centers at W. Roxbury and Brockton. Funding is being provided by the VA.

### **Publications Resulting from This Research**

**None reported.**

# IX. Biomechanics

*For additional information on topics related to this category see also the following Progress Reports: [13], [14], [15], [18], [31], [35], [39], [42], [68], [255], [324].*

## A. General

### [280] Nuclear Magnetic Resonance (NMR), Biochemical and Biomechanical Studies of the Human Foot Pad

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**William Winter, MD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A466-RA)

**Purpose**—Our previous studies with human foot pads indicated that the foot pad tissue consists mostly of triglycerides and that their component fatty acids are more unsaturated than those of triglycerides of other adipose tissues in the body. Increased unsaturation of fatty acids results in decreased viscosity which improves the efficiency of shock absorption.

Our research goals are to: 1) develop a noninvasive method, nuclear magnetic resonance (NMR), which would permit the measurement of the composition of foot pads *in vivo*; 2) continue the biochemical studies of the fibro-fatty tissues of “normal” and abnormal human foot pads obtained at surgery; and, 3) develop a procedure to test the biomechanical properties of footpads *in vivo* and *in vitro*, in an attempt to correlate the biochemical composition with the biomechanical properties of the footpads.

**Methodology**—The NMR instrumentation consists of a 1.89 T, 30 cm horizontal-bore cryomagnet (Oxford Instruments) and a Biospec Spectrometer (Bruker Instruments and Oxford Research Systems). The spectrometer is operated in the Fourier transform mode and is interfaced with an Aspect 3000 computer. The coil is tuned to a resonance frequency of 1 Hz of 80.55 MHz. We have constructed

a device which permits the placement of a foot in a reproducible geometric fashion in the bore of the magnet and maintains the position comfortably for 15 minutes.

**Preliminary Results**—In 15 normal volunteers (6 males and 9 females, age range 29-68 years), the observed value for the water-to-lipid ratio is  $5.90 \pm 1.87$ ; no sex differences were seen. Age differences need additional studies. We also studied 4 females (34-63 years of age) and 4 males (50-54 years of age) before and after running on a treadmill for 20 minutes at 5 miles per hour at 5 percent elevation. In 4 cases we found insignificant increases (less than 20 percent); in 3 cases, insignificant decreases. In one case a significant increase was seen (+59 percent). After exercise, the surface temperatures of the foot increased in all cases with an average of 30.6 degrees prior to and 34.2 degrees after exercise. The results indicate that exercise does not appear to alter the water-to-lipid ratio of the footpads.

Examination of 8 diabetics (4 males and 4 females) revealed that the males exhibited a normal water-to-lipid ratio, whereas the females had a ratio of  $8.47 \pm 2.24$ , statistically different from the normals at the  $P=0.0075$  level. These results are surprising since it is commonly believed that no sex



differences exist in diabetes mellitus. Additional studies of diabetics are planned.

The device for testing the viscoelastic properties of intact footpads in response to stress has been constructed. The appropriate computer software is finished and we are testing human volunteer and cadaver heel pads in an attempt to correlate their footpad mechanical properties results with their water-to-lipid ratio determined by NMR.

Biochemical analysis of footpad tissue obtained at surgery has been expanded to include 38 normals, 8 patients, and one cadaver specimen. All fatty acid

analyses were completed in 1989. Preliminary results indicate no significant changes from our limited previous observations regarding normal footpads. The non-lipid component of the footpads appears to consist mostly of collagen as calculated from their hydroxyproline content.

Analyses of one cadaver heel pad revealed no compositional differences from living "normal" tissues.

#### **Publications Resulting from This Research**

None reported.

### **[281] The Lumbarator: A Real-Time Simulator of Lumbar Muscle Force Distribution**

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**Z. Ladin; S. Guha; C.J. DeLuca**

NeuroMuscular Research Center, Boston University, Boston, MA 02215

**Sponsor:** *VA Rehabilitation Research and Development Service*

**Purpose**—The purpose of this study is to develop a system that displays muscle force distribution in the lower back.

**Progress**—A system was developed to display in real time the distribution of muscle forces in the lower back in response to a generalized gravitational loading. Using a precalculated database of muscle activity surfaces for 22 muscles crossing the L3 level in the lumbar region and a user-interface that

determines the loading condition, the system expresses the load distribution among all the different muscles using a color (or a gray-level) mapping. The user is thus able to study immediately the effect of given loading conditions (or quasi-static exercises) on the muscle force distribution in all the muscles of the cross section of interest.

#### **Publications Resulting from This Research**

None reported.

### **[282] Mechanical Recruitment of Low Back Muscles**

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**Z. Ladin; K.R. Murthy; C.J. DeLuca**

NeuroMuscular Research Center, Boston University, Boston, MA 02215

**Sponsor:** *VA Rehabilitation Research and Development Service*

**Purpose**—The large number of muscles crossing any transverse lumbar cross section (up to twenty-two for the L3 level), and the limited number of equilibrium constraint equations that can be written (only six for the most general case of external force and moment loading) create a mechanically undetermined system. A biomechanical model was developed to study lumbar muscle load sharing for a class of physical tasks that involve gravitational loading (holding weights) of the upper body in erect posture.

The model assumes that the lumbar muscles balance externally applied flexion and lateral bending moments. The concept of a "loading plane," whose axes are the two bending moments, was introduced such that any point in the plane can be viewed as a "loading-point" describing a combination of bending moments applied to the body.

**Methodology**—An approach was developed that summarizes the activity of a single muscle caused by

an arbitrary gravitational loading in erect posture and with no external torsion as a muscle activity surface (MAS). This is a surface that describes the individual muscle force to a given combination of two independent moments: flexion and lateral bending. The two moments describe the two axes of the "loading plane" over which the MAS of a given muscle is spun.

**Results**—The study of lumbar-muscle load sharing revealed loading conditions that required activation or deactivation of a particular muscle. The loading plane could thus be divided into regions of activity and inactivity for each muscle separated by a "switching curve." This concept proved very useful for examining previously described physiological assumptions on the loading conditions of particular muscle groups and for grouping the twenty-two muscles described in the model into ten functional units. Electromyographic (EMG) validation studies

were conducted and showed a high degree of correlation between the model predictions and actual measurements for the contralateral (with respect to the load) muscles and a lesser degree of correlation for the ipsilateral muscles.

#### **Publications Resulting from This Research**

**Low Back Muscle Force Prediction Using Activity Surfaces and Switching Curves.** Murthy KR, Ladin Z, in *Proceedings of the Tenth Annual Conference of IEEE/Engineering and Medicine in Biology Society*, New Orleans, LA, 641-642, 1988.

**EMG Validation of Lumbar Muscle Activity Surfaces.** Murthy KR, Ladin Z, in *Proceedings of the Tenth Annual Conference of IEEE/Engineering and Medicine in Biology Society*, New Orleans, LA, 643-644, 1988.

**Mechanical Recruitment of Low Back Muscles: Theoretical Predictions and Experimental Validation.** Ladin Z, Murthy KR, DeLuca CJ, *Spine* (in press).

#### **Awards**

**1989 Volvo International Award in Biomechanics,** *International Society for the Study of Lumbar Spine.*

### **[283] Force Transducer Design**

**A. Rodrigues; L.D. Gilmore**

NeuroMuscular Research Center, Boston University, Boston, MA 02215

**Sponsor:** *VA Rehabilitation Research and Development Service*

**Purpose**—Many research projects undertaken at the Neuromuscular Research Center require accurate measurement of force or torque produced during muscle contractions. The magnitude of these forces ranges from less than one pound for measurements of finger flexion to over 400 pounds produced during contractions of the lower back muscles.

**Progress**—In order to accommodate the wide range of force measurement applications, we are developing a force transducer system consisting of commer-

cially available load cell sensors coupled with a force conditioning module. The force conditioning modules developed in our electronics lab process the force signal from the load cells so that they are suitable for digitizing by a computer or recording on analog tape. All laboratories at the Center will adopt this new technology to improve the accuracy and reliability of their force measurements.

#### **Publications Resulting from This Research**

**None reported.**



## [284] Biomechanical Measurements for Quantitative Assessment and Diagnosis of Dysphagia

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Edwin Shaw Hospital, Akron, OH 44312

**Sponsor:** *Edwin Shaw Hospital*

**Purpose**—Dysphagia is a swallowing disorder resulting from neurological impairment. It presents a major problem in the comprehensive rehabilitation of patients with stroke and other head injuries. Further, dysphagia often leads to several clinical problems such as aspiration, dehydration, and inadequate nutrition. Identification of the patient at risk of aspiration is important from a clinical standpoint.

The swallowing process can be divided into three distinctive phases: oral, pharyngeal, and esophageal phase. We are developing procedures for quantitative assessment and diagnosis of dysphagia involving the oral and pharyngeal phases.

**Progress**—We have identified and developed techniques to measure several biomechanical parameters which aid in the quantitative assessment of the oral musculature in dysphagia. These parameters include: 1) lip closure pressure; 2) lip interface shear force; 3) tongue thrust in forward, backward and two lateral directions; and, 4) swallow pressure.

For the quantification of the pharyngeal phase, two ultra-miniature accelerometers were placed on the outside of the throat. In addition, the swallow pressure was monitored with a catheter placed at the base of the tongue and connected to a pressure transducer. Normal subjects and dysphagic patients were measured for acceleration and swallow pressure simultaneously.

**Preliminary Results**—We found statistically significant differences in the above parameters measured in normal and dysphagia patients. In current clinical practice, the strength of the oral musculature is assessed using tongue depressors and lollipops. The biomechanical parameters devised in the present investigation can aid the physician to objectively assess the recovery of the dysphagic patient.

Swallowing in normal individuals gave rise to a characteristic acceleration pattern which could be well reproduced. The amplitude of acceleration varied from 1 to 2 g. There was no time lag between the appearance of the pressure wave and the appearance of the acceleration wave characteristic of swallowing.

By contrast, in 35 dysphagic patients the characteristic acceleration pattern was either absent or significantly delayed. The amplitude of acceleration varied from 0 to 0.5 g. In those patients who could trigger a swallow, we found significant lag times between the acceleration and pressure waveforms. Additionally, in six patients we measured the biomechanical parameters upon admission, and after 3 weeks of thermal exercise therapy. We found significant improvements in the acceleration amplitude and pattern after the 3 week therapy. We found similar improvements in oral biomechanical parameters (tongue thrust, lip pressure, etc.) after 3 weeks of oromotor exercises. These results correlated well with bedside clinical evaluation.

**Implications**—The biomechanical parameters identified and the measurement techniques developed in this study can be used for quantitative evaluation of the patient and for patient training to speed up the recovery process.

In current rehabilitation practice, the pharyngeal phase and coordination are assessed using videofluoroscopy (radiography) which is often very expensive. Our results from the dysphagia patients correlated well with the bedside clinical evaluation. Acceleration, when measured simultaneously with the swallow pressure measurement, gives a quantitative picture of the coordination of the swallowing mechanism and can be used in the diagnosis of dysphagia. We are currently in the process of correlating the biomechanical results with the videofluorographic examination.

### Publications Resulting from This Research

**Biomechanical Measurements for Diagnosis and Assessment of Dysphagia.** Reddy NP, Rane MB, Canilang EP, Casterline J, in *Proceedings of the 9th Annual Conference of IEEE Engineering in Biology and Medicine*, Boston, MA, 473-474, 1987.

**Accelerometry: A Technique for Noninvasive Diagnosis of Dysphagia.** Canilang EP, Reddy NP, Joshi AM, Casterline J,

Candadai RS, in *1988 Annual Conference of American Congress of Rehabilitation Medicine*, Seattle, WA, 1988.

**Biomechanical Quantification for the Assessment and Diagnosis of Dysphagia.** Reddy NP, Canilang EP, Grotz RC, Rane MB, Casterline J, Costarella BR, *Eng Med Biol* 7:16-20, 1988.

**Biomechanical Measurements to Characterize the Oral Phase of Dysphagia Patient.** Reddy NP, Costarella BC, Canilang EP, Grotz RC, *IEEE Trans Biomed Eng* (in press).

## B. Bone and Joint Studies

### [285] Patient-Specific Finite Element Modeling of Bone from CT Scan Data

**Harry B. Skinner, MD, PhD; Joyce H. Keyak, BSME; Christopher E. Cann, PhD; C. Daniel Mote, PhD**  
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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A371-2RA)

**Purpose**—The objective of this project is to develop, verify, and document accurate methods for deriving the mechanical properties of inhomogeneous bone from CT scan data for the definition of three dimensional (3-D), patient-specific finite element (FE) models. Several methods of evaluating the mechanical properties of the finite elements will be examined, including a new method based on the hypothesis that orthotropic mechanical properties of an element of bone can be derived by treating each element as a composite of subelements; each subelement would have a modulus computed from the fraction of bone in its volume. The accuracy of the modeling of the bone properties will be determined through comparison of the predictions of FE models and the results of mechanical tests of bone specimens.

**Methodology**—The study will be divided into two parts. First, homogeneous specimens of human trabecular bone will be identified, CT scanned, and mechanically tested. Existing relations for predicting

the mechanical behavior of bone using CT scan data will be compared to the measured data. In addition, the new method for deriving orthotropic material properties of the specimens will be developed. This initial phase will establish the accuracy of predicting the behavior of bone of proven homogeneity so that the techniques can be extended to the FE modeling of inhomogeneous bone.

The second part of the study will involve mechanical testing and FE modeling of inhomogeneous bone specimens. The existing and newly-developed relations for predicting the mechanical properties of bone from CT scan data will be used to generate several FE models of each bone specimen. Each specimen will be mechanically tested and its measured stiffness will be compared with the values predicted by its FE models. The accuracy and precision of each method of FE modeling will be assessed.

### Publications Resulting from This Research

None reported.



## [286] Load-Bearing Characteristics of the Wrist with Intercarpal Arthrodesis

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A502-RA)

**Purpose**—Scaphoid-capitate (SC) and scaphoid-trapezium-trapezoid (SIT) intercarpal fusions have been advocated in the treatment of common carpal and intercarpal disorders (Kienböck disease, rotary subluxation of the scaphoid). The relative merits of each remain the subject of laboratory and clinical study. Recent reports suggest a similar range of residual motion remains after SC or SIT intercarpal arthrodesis. Definition of alterations of load distribution across the radiocarpal surface with either SC or SIT arthrodesis may help clarify the role of each. It has been further suggested that both the short- and long-term results of either SC or SIT fusion may be directly related to the posture of the scaphoid within the intercarpal fusion mass. This investigation studies: 1) the effect of SC and SIT fusions upon radiocarpal load transmission; and, 2) the effect of altered scaphoid alignment within the SC or SIT fusion mass upon radiocarpal load transmission.

**Progress**—Fresh frozen cadaveric forearms were mounted on a loading fixture. Super-low Fuji pressure-sensitive film was inserted into the radiocarpal joint through a dorsal capsulotomy. An Instron testing machine was used to apply an 18.2 kg load over two minutes through wrist flexor and extensor tendons. SC and SIT intercarpal fusions were simulated by external fixator stabilization. The scaphoid was positioned in: 1) neutral (45 degrees flexion relative to the long axis of the capitate); 2) palmar flexion (60 degrees flexion); and, 3) extension (20 degrees flexion). X-rays confirmed absence of bony abnormalities, pin placement, and scaphoid

posture. Fuji film-chip images were video-captured and computer digital analysis performed. Each test was repeated three times for three specimens. Each specimen was evaluated with the wrist in five positions: neutral, ulnar deviation, radial deviation, 45 degrees of palmar flexion, and 45 degrees of dorsiflexion. A total of 2,145 film chips were analyzed.

**Results**—Our results suggest that: 1) radiocarpal load distribution patterns are similar with SC and SIT intercarpal arthrodesis; 2) SC and SIT fusions with the scaphoid in the “reduced” position stiffen the radial column, shifting load to the radioscapoid articulation and away from the radiolunate fossa; 3) position of the scaphoid within each fusion profoundly affects the load transmission across the radioscapoid and radiolunate surfaces; 4) palmar flexion of the scaphoid within the fusion unloads the radioscapoid articular surface; and, 5) extension of the scaphoid within the fusion unloads the radiolunate articular surface.

**Future Plans**—The study is being repeated in a second group of cadaver wrists with scaphoid ligamentous instability as we have previously defined.

### Publications Resulting from This Research

**Radiocarpal Articular Contact Characteristics with Scaphoid Instability.** Blevens AD, Light TR, Jablonsky WS, Smith DG, Patwardhan AG, Guay ME, Woo TS, *J Hand Surg* 14A(5):781-790, 1989.



## [287] Determination of the Effects of Implant Interface Mechanics on Bone Remodeling

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Sponsor: VA Rehabilitation Research and Development Service (Project #A160-2RA); New York State Department of Health

**Purpose**—The objective of this study is to gain knowledge about the biomechanical and physiological reactions of bone in relation to local mechanical stresses at the interface between bone and an orthopaedic implant.

**Methodology**—Interfacial biomechanics are documented by finite element analyses and mechanical tests, then compared with interfacial tissue reactions measured by histomorphometric methods to reveal correlations between interfacial biomechanics and bone remodeling. Because joint replacements depend on secure and permanent fixation to bone, this project represents an unusual attempt to improve implant design by examining the effect of local interfacial biomechanics on interfacial bone.

Experimentally, we have established an *in vivo* model of a bone-titanium interface which can be investigated under known biomechanical conditions. Three types of experiments were planned. In "loading" experiments, we start with control interfaces that form around special titanium screw implants (Branemark fixtures) in canine bones during a period of mechanically undisturbed healing. Then, we challenge these interfaces mechanically by applying a programmed load waveform to test implants *in vivo* by an MTS machine.

"Micromotion" experiments *in vivo* were designed to determine the effects of controlled micromotion on the interface of smooth-surfaced titanium cylinders and bone.

Finally, because we need accurate data on the mechanical nature of the connection between bone and a titanium surface, we designed bonding experiments to measure the "bonding" via a tensile test method. These tests compare smooth-surfaced titanium washers with hydroxylapatite (HA)-coated titanium washers (of the same surface roughness) that are implanted into surgically prepared "wells" in canine femoral diaphyses. After approximately 7-months' implantation, they are pulled off (perpendicular to the interface) via an MTS load frame.

This tensile test is a change from our previously proposed push-out shear tests using cylinders in bone. This change was made because our data, and that from our studies, indicate that the interfacial stress state push-out tests are highly dependent on the ratio of the specimen-to-hole diameter and test boundary conditions. This in turn makes it difficult to interpret the results in terms of a single interfacial shear stress value.

**Preliminary Results**—*Loading Experiments (screw implants)*. The first series of experiments (100 N peak loads) failed to reveal statistically significant histometric differences between loaded and control interfaces at 2-3 weeks after the end of the loading period. Nevertheless, a trend was observed toward less bone-titanium apposition (greater resorption) at loaded interfaces. To investigate further the significance of load magnitude, we measured ultimate and fatigue strengths of screw-bone interfaces in samples of dead bone. For 3.5 mm diameter Branemark fixtures placed transcortically in canine long bones, we measured ultimate pull-out strengths of  $1450 \pm 190$  N for fresh-frozen tibiae. Furthermore, fatigue tests suggested that interfaces could fail due to accumulated damage at  $10^3$  cycles for axial forces as low as 600 N. It was concluded that a load amplitude of 300 N would represent a maximum mechanically safe challenge to bone at the interface. In a further series of *in vivo* tests aimed at obtaining a more definitive biological response, we have successfully completed the *in vivo* loading phase (using 300 N) in a group of 6 dogs, and are evaluating specimens at 5 weeks and 12 weeks after the loading period. We also have 4 additional dogs with 4 fixtures implanted, to be used in final confirmatory loading trials.

*Micromotion Experiments*. The *in vivo* experiments originally planned for this study were suspended because preliminary bench tests showed the force required to move smooth-surfaced titanium cylinders in holes drilled transcortically in canine



long-bones was highly variable. We have found that the measured force depends critically on the degree of misfit of the cylinder in the surgically-prepared hole; this effect makes the starting conditions of the experiment difficult to reproduce from sample to sample.

**Bonding Experiments.** There are at least two complicating factors in using "interfacial shear strength" measurements to evaluate "bonding." One factor is the influence of mechanical interlocking between a titanium cylindrical plug and a hole drilled in bone. Another factor is the nature of any interfacial physical/chemical bonding. Based on the above-noted mechanical tests of cylinders in the micromotion experiment, our data indicate that so-called push-out tests of cylinders in bone are highly sensitive to misfit. Also, depending on the boundary conditions of the push-out test, the interfacial stress states can significantly depart from a simple shear interpretation. For these reasons, we devised a tensile pull-off in which small washers of smooth-surfaced pure titanium or HA-coated titanium, are held down mechanically onto a prepared site in canine femora. Following a healing period, a small pin is attached to the washer to permit the washer to be pulled off perpendicular to the plane of

the interface. We have implanted 12 titanium washers and 12 HA-coated washers in 8 canine femora (4 dogs). Pull-off tests are scheduled at 2.5, 3.5, and 7 months.

**Future Plans**—All phases of the loading, micromotion, and bonding experiments under this project are expected to be completed by Winter 1990.

#### Publications Resulting from This Research

**Histomorphometry of "Osseointegrated"-Type Interfaces Subjected to Different In Vivo Loading Protocols.** Hipp JA, Brunski JB, Cochran GVB, in *Proceedings of the 13th Annual Meeting of the Society for Biomaterials*, 48, New York, NY, 1987.

**Investigation of "Osseointegration" by Histomorphometric Analyses of Fixture-Bone Interfaces.** Hipp JA, Brunski JB, Cochran GVB, Higuchi KW, *J Dent Res* 66:186, 1987.

**Method for Histological Preparation of Bone Sections Containing Titanium Implants.** Hipp JA, Brunski JB, Cochran GVB, *Stain Technol* 62(4):247-252, 1987.

**The Influence of Force, Motion, and Related Quantities on the Response of Bone to Implants.** Brunski JB, in *Non-Cemented Total Hip Arthroplasty*, 7-21, R.H. Fitzgerald, Jr. (Ed.), New York: Raven Press, Ltd., 1988.

**Pull-Out and Fatigue Failure of Bone-Dental Implant Interfaces.** Hoshaw SJ, Brunski JB, Cochran GVB, in *1989 Biomechanics Symposium*, P.A. Torzilli, M.H. Friedman (Eds.), AMD 98, American Society of Mechanical Engineers, 1989.

## [288] Pathokinesiology of Anterior Cruciate Ligament Deficiency

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A178-3RA)

**Purpose**—The objective of this project is to investigate the deviations from normal kinematics and muscle function in knees with ruptured anterior cruciate ligaments and the kinematics of the surgically reconstructed knee. Measurements are made using 6-degree-of-freedom goniometry and electromyography during walking and pivoting.

**Progress**—The knee kinematics and muscle patterns of 16 individuals with surgically reconstructed knees have been added to the database containing information from 25 individuals with uninjured knees and 20 individuals with injured knees. The kinematics were quantitated using helical motion analysis. The most difficult part of assessing and explaining

the abnormal knee motions has been representing them in terms of anatomic variables in addition to helical motion variables. A technique has been developed which compares the motions of individual knee joints with respect to a composite normal profile, and expresses any differences in anatomic variables. Our expanded database is being re-analyzed with this technique.

Once the differences have been calculated it is necessary, because of population variability, to ascertain whether any differences are significantly different. A large effort has been expended to study the appropriateness of various parametric and nonparametric statistical tests that could provide this information.



**Preliminary Results**—Sufficient testing indicates that the population data of helical motions is Gaussian and populations can be compared using the Behrens-Fisher algorithms for unequal group sizes and unknown mean vectors and covariance matrices. The statistical testing has just been completed. The results show that tight injured knees have kinematics resembling uninjured knees whereas loose injured knees are vastly different. The kinematics of surgi-

cally reconstructed knees are more normal than those of loose injured knees but not as “normal” as those of tight injured knees.

**Future Plans**—Work is continuing to anatomically represent these results.

**Publications Resulting from This Research**

None reported.

## [289] Functional Kinesiology of Knee Bracing

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A386-RA)

**Purpose**—The objective of this project is to investigate the effects of 5 functional braces on the kinesiology of the injured knee. Measurements will be made using a 6-degree-of-freedom goniometry and electromyography during walking and pivoting.

**Progress**—A 6-degree-of-freedom goniometer had been designed, fabricated, and tested in previous years. The goniometer underwent many design changes and tests in order to insure that: 1) it can be mounted around the knee joint braced with a variety of orthoses; 2) the measurements are not affected by soft tissue motions; and, 3) it does not make contact with the orthoses.

**Implications**—Present efforts have been devoted to refining a calibration and measurement protocol in order to measure kinematic motions of specific anatomic points. In the long term, this will result in the ability to measure the relative motions of points on the tibial and femoral articulating surfaces. Presently, it provides the motions of tibial landmarks with respect to femoral landmarks.

**Publications Resulting from This Research**

None reported.

## [290] In Vivo and In Vitro Mechanical Behavior of the Normal and Degenerated Lumbar Spine

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A095-4RA)

**Purpose**—The objective of this study was to characterize the static and dynamic load-sharing capability of the normal and degenerated lumbar spine unit. Analysis of the results will focus on the: 1) interdependence between disc and vertebral body properties; 2) degenerative conditions which compromise the normal joint function; 3) development of clinical assessment techniques for predicting the mechanical

condition of the human lumbar spine; and, most importantly, 4) role of mechanical dysfunction in chronic low back and sciatic pain. Based on these results, at-risk criteria will be developed for management and prevention of low back disorders.

**Progress**—*In vivo* acute and chronic animal studies and *in vitro* human cadaveric anatomical studies



were performed. These studies were designed to assess: 1) the *in vivo*, *in situ*, and *in vitro* mechanical behavior of the normal immature porcine vertebral unit; 2) the acute *in vivo* mechanical behavior of surgically-injured (chemonucleolysis, nucleotomy, annulus injury) immature porcine spinal units; 3) the chronic *in vivo* mechanical behavior of adult porcine spinal units following three-level fusion, bilateral facetectomy and semi-rigid (constant load) vertebral body fixation; and, 4) the chronic *in vivo* mechanical behavior of immature porcine spinal units following bilateral facetectomy.

A specially-designed loading apparatus was used to apply compressive loads to the vertebral unit via pins inserted into the L1 and L3 vertebral bodies. Creep-recovery curves were obtained prior to, and immediately following, disc injury in the acute groups; or prior to, and one-month post surgery in the chronic groups.

A three-dimensional anatomical model of the geometry and material distribution of a normal human lumbar spine was constructed from two-dimensional transverse cross-sections of the spine.

**Results**—Comparison of the acute *in vivo*, *in situ* and *in vitro* mechanical behavior of the lumbar spine indicated that the lumbar spine was more compliant and deformed at a more rapid rate *in vivo* than *in vitro* or *in situ*, reflecting the oscillatory, conditioning effects of blood flow and respiration. Acute chemonucleolysis, annular injury, and nucleotomy reduced the stiffness and increased the rate of deformation of the vertebral unit, whereas chronic facetectomy and fusion increased the stiffness and decreased the rate of deformation of the vertebral unit. This study raises many questions concerning the ability to reliably predict the mechanical behavior of the lumbar spine on the basis of information obtained during *in vitro* test conditions, and indicates a need for the standardization of experimental methods, since physiological conditions play important and significant roles in the normal, time-dependent mechanical response of the lumbar motion segment.

Analysis of the material distribution (volume fraction of bone) within the human vertebral centrum revealed a highly anisotropic distribution of

trabecular bone characterized by five primary morphological levels (superior-inferior). Anterior-posterior variations within each level were also noted. The differences in trabecular morphology have important clinical implications in terms of the level at which screws, braces, rod instrumentation, and other hardware are mounted during surgery; the choice of a site for biopsy or density scan; and, the type and severity of fractures. These results suggest that an anisotropic distribution of trabecular material should be used for analytical studies of the mechanical behavior of the lumbar spine.

**Future Plans**—We are currently developing a technique for generating three-dimensional anatomically-correct finite element models of the human lumbar spine from computer tomography (CT) data, magnetic resonance imaging (MRI) images and tissue sections. These models will be used to predict the mechanical behavior of the spine following aging, disease, injury, and surgical interventions. Model predictions will be compared to the results of animal experimental and human cadaveric tissue studies conducted in our lab. Longer term chronic animal studies are also being planned and will include studies of biological fixation and bone remodeling using a flexible vertebral prosthesis.

#### Publications Resulting from This Research

- A Study of the Compressive Properties of Lumbar Vertebral Trabeculae: Effects of Tissue Characteristics.** Hansson TH, Keller TS, Panjabi MM, *Spine* 12:56-62, 1987.
- Mechanical Behavior of the Human Lumbar Spine. I. Creep Analysis During Static Compressive Loading.** Keller TS, Spengler DM, Hansson TH, *J Orthop Res* 5:467-478, 1987.
- Mechanical Behavior of the Human Lumbar Spine. II. Fatigue Strength During Dynamic Compressive Loading.** Hansson TH, Keller TS, Spengler DM, *J Orthop Res* 5:479-487, 1987.
- Fatigue Fracture Morphology in Human Lumbar Motion Segments.** Hansson T, Keller T, Jonson R, *J Spinal Disord* 1:33-38, 1988.
- In Vivo Creep Behavior of the Normal and Degenerated Porcine Intervertebral Disc: A Preliminary Report.** Keller TS, Hansson TH, Holm S, Pope MM, Spengler DM, *J Spinal Disord* 1:267-278, 1989.
- Flexible Device for Vertebral Body Replacement.** Main JA, Wells ME, Spengler DM, Strauss AM, Keller TS, *J Biomed Eng* 11:113-117, 1989.
- Regional Variations in the Compressive Properties of Lumbar Vertebral Trabeculae.** Keller TS, Hansson TH, Abram AC, Spengler DM, Panjabi MM, *Spine* (European edition) (in press).



## **[291] Psychomotor Test to Evaluate Hand Sensory Substitution Devices: A Pilot Study**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A984-PA)*

**Purpose**—The objective of this study is to develop, construct, and test a pinch force psychomotor task and associated apparatus useful for evaluating sensory substitution force feedback devices for the upper extremity. Reliability and sensitivity of a psychomotor test paradigm for studying pinch force control will be tested.

**Methodology**—The study will focus on construction of an isometric strain gauge pinch dynamometer which can be interfaced to a microcomputer. During this development phase it will be tested by using it to measure pinch force control on 10 normal subjects. After the completion of this pilot to construct and test with normals, a project will be done to use the device to measure performance differences between normals and individuals having sensory deficits in

the hands. Data from the subsequent project will provide an indication as to whether the task proposed is sensitive to force control effects associated with the insensate hand. The effect of performance degradation between normal and patient populations will then be compared.

**Progress**—An isometric strain gauge pinch dynamometer is being designed, constructed, and interfaced to a microcomputer. Software is being developed for controlling the test apparatus and administering the pinch force psychomotor test. Performance measurements include reaction time, time to peak force, peak force, and overgrip force.

### **Publications Resulting from This Research**

None reported.

## **[292] Performance Parameter Identification and Synthesis of Upper-Limb Motion**

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**Sponsor:** *Easter Seal Research Institute*

**Purpose**—The purpose of this study is to measure and identify some of the important task dependent performance characteristics of point-to-point, unconstrained three-dimensional upper-limb motion. Simulation of this point-to-point motion, via optimization of predefined performance characteristics, will then be used in an attempt to help identify some of the possible control characteristics of upper-limb motion. Specific goals are to identify the important kinematic and dynamic performance measures of arm motion, and use the previous experimentally determined performance objectives of upper-limb motion in a multi-variable cost function in an attempt to synthesize the upper-limb motion given certain initial, final, and boundary conditions.

**Methodology**—Reaching studies with three normal subjects have been carried out. These reaching tasks are point-to-point movements under varying conditions of target location with the initial and final conditions being specified. No external disturbances are present during the movement. Three individuals have performed four different upper-limb movements. The upper-limb kinematics were measured using the VICON position detection system. Hand switches were used to measure the temporal factors of the motion. Three-dimensional kinematic, anthropometric, and hand switch information was used in an inverse dynamic analysis to determine the joint reaction forces and moments for the shoulder, elbow, and wrist joints.



**Results**—Comprehensive models of the upper limb have been used to determine various kinematic and dynamic characteristics. Kinematic measures included: hand path curvature, torsion and speed; three-dimensional joint angular displacement, velocity, and acceleration; two- and three-dimensional hand path plots; and phase plane plots. Dynamic measures included: mechanical energy expenditure of the upper limb joints; quasi-mechanical work of all the joints with and without energy transfers; kinetic and potential energy; power expenditure and rate of power utilization of the individual joints; and joint torques. Means and standard deviations of typical results obtained for the different motions averaged over five consecutive runs for medium and fast motions.

**Future Plans**—These kinematic and kinetic characteristics, which are needed to characterize the observed upper-limb motions, will be incorporated into an analysis of the possible optimal motion trajectory planning techniques employed by the central nervous system (CNS) to control voluntary coordinated movement.

#### **Publications Resulting from This Research**

**Three-Dimensional Upper Limb Kinematics.** Lipitkas J, Naumann S, in *Proceedings of the 13th Canadian Medical and Biological Engineering Conference (CMBEC)*, Halifax, 73-74, 1987.

### **[293] Quantitative Functional Anatomy of the Human Shoulder**

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**Sponsor:** *Innovative Research Programme for the Disabled/Aids for the Handicapped*

**Purpose**—Quantitative data on the musculoskeletal system of shoulder and arm are needed with a view to: 1) analysis of movements of shoulder girdle and arm, based on arm movement registration in activities such as wheelchair driving; 2) analysis of movements of the shoulder girdle and arm in activities of daily living (ADL) and vocational activities; 3) predictions of outcome of arthrodesis of the shoulder in patients with a lesion of the brachial plexus; and, 4) aiding interpretation of *in vivo* human palpation data.

**Methodology/Results**—The cadaver measurement data were used to run a model which is based on finite element analysis and comprised a dynamic version of this method (SPACAR). The model was used to describe the movements of the bones of the shoulder girdle and arm with respect to each other and with the trunk. The data on muscles were analyzed: the estimated physiological transsections

correlated well with muscle mass with some exceptions. Left/right differences were not found.

The accuracy of the model was tested. The location of the center of rotation of the humeral head was computed. The function of the coracoclavicular connections was analyzed from earlier determinations of the position of the bones of the girdle in relation to each other and to the trunk in various positions of the arm. The conclusion is that the model as well as the methods employed to feed parameter values to the model are working well.

**Future Plans**—Application to normal and abnormal shoulder and arm movements in patients with various ailments, manual wheelchair propulsion studies, and ergonomic problems is planned.

#### **Publications Resulting from This Research**

None reported.

## [294] Comprehensive, Quantitative, Predictive Model of the Human Knee Joint

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**Sponsor:** *National Science Foundation*

**Purpose**—The human knee is modeled using screw and wrench theory as a set of experimentally-measured passive constraints—the articular surfaces, the menisci and the ligaments—in order to define the total freedom of the joint, i.e., the volume which bounds the movement potential of the femur relative to the tibia. No *a priori* assumptions as to kinematics or loading are made; the estimated volume and resulting degrees of freedom predicted are then compared to human kinematic data acquired *in vivo* using markers mounted on bone pins.

**Methodology**—The invasive bone pin data set is compared with data from markers and arrays mounted noninvasively on the skin to establish how soft tissue movement differs from skeletal data and thereby affects gait data accuracy.

The passive model of the knee is to be inserted into a musculoskeletal model of the lower extremity. The collective action of the multiple muscle actuators will determine the specific trajectories, or progression of instantaneous helical axes which the knee generates during movement and loading. For the muscle model, a method has been developed for predicting the level of agonist-antagonist co-contraction necessary for joint impedance control, by adding a stability criterion to other cost or penalty functions in the optimization analyses which partition the joint forces into the individual muscle forces.

### Publications Resulting from This Research

**A Comparison of Skeletal Kinematics Measured In Vivo Using Different Methods for Attaching Markers:** Work in Progress.

Murphy MC, Dube N, Zarins B, Jasty M, Mann RW, *Third Annual East Coast Clinical Gait Conference*, Bethesda, MD, 1987.

**A Comparison of Smoothing and Digital Filtering/Differentiation of Kinematic Data.** Murphy MC, Mann RW, in *Proceedings of the 9th Annual Conference of the IEEE/EMBS*, Boston, MA, 1987.

**Comparison of Finite Helical Axis Estimation to Instantaneous Helical Axis from Noisy Kinematic Data.** Van der Meulen M., Bachelors Thesis, Massachusetts Institute of Technology, 1987.

**An Evaluation of Different Methods for Obtaining Derivatives of Noisy Kinematic Data.** Murphy MC, Schwartz S, Mann RW, *Third Annual East Coast Clinical Gait Conference*, Bethesda, MD, 1987.

**Comparison of Finite Helical Axis Estimation to Instantaneous Helical Axis from Noisy Kinematic Data.** Van der Meulen M, Murphy MC, Mann RW, *Transactions of the 34th Annual Meeting of ORS*, Vol. 13, Atlanta, GA, 1988.

**A Feasibility Study of Using Form Birefringence to Determine the Material Properties of Meniscal Tissue.** Schubert SA, Bachelors Thesis, Massachusetts Institute of Technology, 1988.

**The Instantaneous Helical Axis and Its Application to Motion.** Karlsson JOM, Bachelors Thesis, Massachusetts Institute of Technology, 1988.

**Measurement of Ligament Tissue Cross-Sectional Area.** Lanzendorf EJ, Murphy MC, Mann RW, *Proceedings of the 14th Annual NE Bioengineering Conference*, University of New Hampshire, Durham, NH, 22-25, 1988.

**A Method for Estimating the Total Freedom of the Knee.** Murphy MC, Mann RW, *Modeling and Control Issues in Biomechanical Systems*, ASME Winter Annual Meeting, Chicago, IL, DSC-12, BED-11:55-65, 1988.

**Passive Constraint Analysis of the Knee.** Murphy MC, Mann RW, *Proceedings of the 14th Annual NE Bioengineering Conference*, University of New Hampshire, Durham, NH, 36-39, 1988.

**Optical Verification of a Technique for In Situ Ultrasonic Measurement of Articular Cartilage Thickness.** Modest VE, Murphy MC, Mann RW, *J Biomech* 22(2):171-176, 1989.



## [295] Establishing the Reliability and Validity of an X-ray Measure for Shoulder Subluxation

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**Sponsor:** *National Health Research and Development Programme*

**Purpose**—The objective of this study is to test the reliability and validity of a new X-ray method of measuring shoulder subluxation. The method involves positioning the patient in a specially-constructed chair and taking an X-ray from a standardized position. This will produce a uniform film from which angles and distances can be measured with precision.

Specifically, we will test: 1) the construct validity of the X-ray method by comparing the measurements obtained for patients with clinically-subluxed shoulders to those without any clinical signs of subluxation; 2) the concurrent validity of the X-ray method by comparing measurements obtained of subluxed shoulders with occupational therapist's clinical measures of shoulder subluxation; 3) the intra-rater reliability of positioning the patient in the chair by having two teams of therapists position patients and comparing the measurements obtained from X-rays of a patient's subluxed shoulder; 4) the intra-rater reliability of positioning the patient in the chair by having the same team of therapists position patients twice and comparing the measurements obtained from X-rays of a patient's subluxed shoulder; 5) the inter-rater reliability of the X-ray reading by comparing measurements made by four therapists from a single X-ray; and, 6) the intra-rater reliability of the X-ray reading by comparing measurements made twice by a therapist from a single X-ray.

**Methodology**—Data will be collected from 36 stroke patients who have subluxation on clinical examination, and 36 patients who do not. Patients who do not have subluxation will participate in the valida-

tion phase (Objective 1). Patients who have a subluxation will participate in the validity and inter- and intra-rater reliability studies (Objectives 2 to 6). Patients exhibiting a subluxed shoulder on clinical examination will be randomly allocated to participate in either the inter-rater or intra-rater study. Patients in whom inter-rater reliability is to be assessed will be clinically examined, and subsequently positioned for X-ray by each of two teams of therapists with a rest interval. Patients in whom intra-rater reliability is to be assessed will be clinically examined and subsequently positioned twice by the same team of therapists with a rest interval.

The dependent variables, distance and angle of subluxation, will be measured on a ratio scale. If the values obtained from the X-ray readings are normally distributed, then parametric statistics like the *t*-test, analysis of variance *F* test, Pearson's, or intraclass correlation coefficients can be used to test the hypothesis.

**Progress**—Pilot study results seem to be normally distributed.

**Implications**—Establishing the reliability of the measure will permit needed research into the effectiveness of therapeutic interventions for subluxation. Specifically, the effectiveness of shoulder supports commonly used in the treatment and prevention of subluxation may be investigated.

### **Publications Resulting from This Research**

None reported.

## [296] Biomechanical Study of Total Knee Replacement

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**Sponsor:** *National Institute of Arthritis and Musculoskeletal and Skin Diseases, National Institutes of Health*

**Purpose**—The objective of this research is to provide biomechanical information on the knee joint that can be used to improve the treatment of arthritis of the knee. Previous work has indicated that biomechanical function can be influenced by the design of a total knee replacement. Recent results suggest a relationship between dynamic functional loading and clinical results in patients with high tibial osteotomies. The goal is to examine the interrelationships between dynamic functional loading, clinical results with total knee replacement, and high tibial osteotomy.

The general hypothesis is that dynamic functional loading is related to postoperative clinical results. Specific goals are to: 1) identify if time related functional biomechanical changes can be correlated with clinical and radiographic changes; 2) identify if corrections exist between preoperative functional biomechanics and postoperative functional biomechanics following total knee replacement; 3) identify if functional loading abnormalities can be associated with the use of cementless fixation of total knee replacement; and, 4) validate initial findings that preoperative knee joint loading is strongly predictive of clinical results in patients with high tibial osteotomies.

**Methodology**—Biomechanical functional testing is conducted for level walking, stair climbing, and chair rising to determine extrinsic joint movement and loading patterns. This information is analyzed independently, as well as provided as input to mathematical and *in vitro* models to analyze intrinsic joint loads. Biomechanical data are correlated with quantitative clinical and radiographic evaluations.

**Progress**—Twenty-one patients with high tibial osteotomy were studied to determine the relationship between knee-joint loading during gait and

clinical outcome. The patients were tested before surgery, 1 year after surgery, and again at an average of 3.2 years after surgery.

**Results**—The results indicate that certain characteristics of preoperative walking are associated with postoperative clinical results. In particular, the moment tending to adduct the knee joint during walking preoperatively was predictive of postoperative clinical results. The adduction moment was reduced in both groups after high tibial osteotomy. The average postoperative adduction moments in the low adduction-moment group were still significantly lower than those in the high-adduction moment group.

The two groups were indistinguishable on the basis of preoperative knee score, initial varus deformity, immediate postoperative correction, age, and weight. However, at an average 3.2 year follow-up, patients with low preoperative adduction moments had substantially better clinical results than did patients with high adduction moments. The low adduction-moment groups had 100 percent excellent or good clinical results, while only 50 percent of the patient in the high adduction-moment group had an excellent or good result. There was a significant recurrence of varus deformity in the patients in the high adduction-moment group.

**Future Plans/Implications**—Ultimately, this information will be useful in identifying functional loading characteristics that correlate with clinical results and radiographic changes. Adaptive mechanisms will be identified and their implication of joint alignment, component fixation, and clinical outcome will be evaluated.

### **Publications Resulting from This Research**

None reported.



## [297] Functional Forces in Normal and Abnormal Fingers

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**Sponsor:** *National Institute of Arthritis and Musculoskeletal and Skin Diseases, National Institutes of Health*

**Purpose**—The overall purpose of this research is to undertake a biomechanical study of normal and pathologic hands to increase basic understanding and clinical application of hand forces. Emphasis is on analysis of extensor mechanism and force distribution, flexor tendon forces and the pulley system, and kinematics and contact area of articular surfaces.

**Methodology**—Tendons are difficult to study biomechanically because of their viscoelastic properties. They may behave in a fluid-like manner or spring-like fashion and their properties vary with changes in loading. A method permitting reliable nonweightbearing and controlled active and passive mobilization was devised in order to closely approximate human flexor tendon conditions and to study the proper treatment of partial flexor tendon lacerations.

The relative effects of immobilization, early protected mobilization, tenorrhaphy, and no repair of flexor tendon healing were evaluated by paired comparisons after a 35-day healing period. Load deformation plots were recorded from specimens from which the tendon breaking strength, stiffness, and energy absorbed were calculated.

**Progress**—Total arthroplasty of the thumb attempts to improve the results of resection or space-occupying arthroplasties which, while providing good pain relief, have offered little thumb stability, strength, or normal motion. Conditions of surrounding joints indicate that this disease process is not always a straightforward clinical presentation and that a variety of surgical options are needed. When joint disease is limited to the trapeziometacarpal (TMC) joint, bone stock is good, and there is no excessive heterotopic bone. Careful analysis of a comparative series between silicone spacers and tendon spacers for trapezium

resection arthroplasty demonstrates that both pinch strength and motion are somewhat less than with total trapezial arthroplasty. Key-type pinch rarely was over 50 percent of the normal and averaged less than 5 kg for both interposition and silicone arthroplasty.

**Results**—This research demonstrates that internal tenorrhaphy adversely affects breaking strength, stiffness, and energy absorbed compared with nonrepaired tendons. Immobilized repaired tendons were 52 percent weaker than nonrepaired tendons, and mobilized repaired tendons were weaker by 42 percent. Early motion resulted in a 26 percent increase in breaking strength compared with repaired tendons.

Immobilized tendons absorbed only 45 percent as much energy, and mobilized repaired tendons, 55 percent less than nonrepaired tendons. Early protected mobilization increased the incidence of repair disruption, but dramatically improved excursion, stiffness, and breaking strength. It also restored the normal smooth gliding surface and decreased adhesion function.

**Future Plans/Implications**—This work has demonstrated that partial flexor tendon lacerations of 60 percent cross-sectional area are optimally treated without tenorrhaphy and with early mobilization. Future studies will further investigate the flexor tendon pulley systems that affect tendon and joint force distribution compared with theoretical and clinical results. The muscle length/tension relationship will be established based on *in vitro* and *in vivo* experiments. This information will provide the basis for improved design of resurfacing arthroplasties and ligament reconstruction.

### **Publications Resulting from This Research**

None reported.



## [298] Musculoskeletal Modeling

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Musculoskeletal modeling has been a focus in our research for over a decade. The accurate kinematics from telemetered rapid acquisition and computation of kinematics (our software known as TRACK) and dynamic calculations using our NEWTON program make feasible the estimation of the time course and *net* force level in the redundant participating muscles producing a movement pattern. However, to make such models subject-specific, the mathematically-expressed models which define the three-dimensional geometry, kinematics, and kinetics physiology of the skeleton, joints, muscles, and ligaments of the human lower extremity must be adjusted to the parameters specific to the patient; for example, bone dimensions, and muscle/tendon origins and insertions. Our computer tomography (CT) and magnetic resonance imaging (MRI) data scans include the information necessary for such individualization of our musculoskeletal model.

The data from the pressure-instrumented prostheses and corroborating evidence from the amputation prostheses study and the posture-and-balance study have made increasingly clear the ubiquity and significance of agonist/antagonist muscle activity (co-contraction) in virtually all postural adjustments and movements. The significance of these findings to gait analysis, joint forces and moments, muscular skeletal modeling, and individual muscle force deter-

mination cannot be underestimated. All extant studies of the above have yielded, or have been based on, the *lower limit* of the forces the muscles provide and the joints experience. Since all such studies start with movement data, i.e., kinematics, they only reflect the *net* muscle forces which cause the motion, due to the muscle moment at the joint. In co-contraction, muscle and joint forces above these net values occur, but these do not contribute to the observed motion. Amputation prosthesis research in our laboratory is showing that co-contraction is essential to the control of impedance or stiffness of the joint, especially when the human interacts with the environment as in the use of tools.

**Results/Implications**—We have developed a new analysis technique to include co-contraction in our optimization analyses which estimate the force-time output of the individual muscles. In such studies a cost or penalty function, for example, energy expenditure, is minimized to find those solutions which also satisfy the constraint equations. A new “stability” cost function requires that the muscle forces and their aggregate, the joint forces, be adequate to keep the body stable during movement maneuvers.

### **Publications Resulting from This Research**

**The Role of Muscles in the Human Knee Joint.** Fijan S, PhD  
Diss, Massachusetts Institute of Technology (in press).

## [299] Mobility Analysis

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The purpose of this study was to develop, demonstrate, and apply a unique data acquisition, quantification, and display system for human movement to meet the following requirements: 1) a normal, natural milieu for the human subject,

minimizing artificial aspects of the experimental environment and the burden on the subject; 2) high precision, three-dimensional kinematic data, with body-segment translations and rotations relative to a laboratory fixed reference frame, at high data frame



rates relative to the frequency components of human movement, in a form suitable for subsequent dynamic analyses; 3) automaticity—no human intervention in data acquisition and quantization; and, 4) real-time processing of kinematic and forceplate data to provide access to kinematic and dynamic results during or immediately after movement.

**Results**—Our telemetered rapid acquisition and computation of kinematics (TRACK) software complements Selspot (or other electro-optical or video cameras) to process the kinematic data, while our NEWTON program uses the kinematic data with forceplate data and body segment inertial properties to estimate the net forces and moments across the skeletal joints.

The TRACK system is operational at the Massachusetts Institute of Technology, Massachusetts General Hospital at Boston University NeuroMuscular Center, and at the University of Bologna. The TRACK program has been reprogrammed in the "C" language and transferred to a Sun 3 Microcomputer System running in UNIX. TRACK data is now available at over 100 Hz for real-time control of experiments requiring movement input. For observational and comparative purposes, TRACK output is displayed as a moving person (together with graphic information) on a Silicon Graphics personal IRIS (4D20) at 20 Hz. A version coded for personal computers is offered commercially by OsteoKinetics, Inc., in Newton, MA.

The study of optimal post-processing has clearly demonstrated the advantage of smoothing over filtering. We are now comparing position data acquired with TRACK arrays mounted non-invasively on the body segments with arrays on bone pins into the skeleton *in vivo*. These are compared with the usual practice of other gait laboratories, that of mounting "joint center" markers on bony prominences at each of the lower extremities.

With fixed position cameras, the viewing volume for accurate data is about 2 meters on the side, or 1 gait cycle. To study stride-by-stride variability and other non-cyclical and wider ranging movement patterns, we have been developing Large Volume TRACK. The fixed cameras now observe the subject via computer controlled mirror systems which rotate

to keep the LED array images aligned to the camera axes as the subject moves throughout a much larger viewing volume.

### Publications Resulting from This Research

**Comparison of Finite Helical Axis Estimation to Instantaneous Helical Axis from Noisy Kinematic Data.** Van der Meulen M, Bachelors Thesis, Massachusetts Institute of Technology, 1987.

**A Comparison of Smoothing and Digital Filtering/Differentiation of Kinematic Data.** Murphy M, Mann RW, *9th Annual IEEE/EMBS Conference*, Boston, MA, 1987.

**Estimation of Camera Positions and Orientations Using a Control Distribution of Unknown Relative Geometry.** Fijan RS, Mansfield PK, Mann RW, *American Society of Mechanical Engineers Winter Annual Meeting*, Boston, MA, 1987.

**Internal Calibration of Opto-Electronic Cameras.** Mansfield PK, Fijan RS, Mann RW, in *Proceedings of the 9th Annual IEEE/EMBS Conference*, Boston, MA, 1987.

**Opto-Electronic Camera Image Plane Calibration.** Mansfield PK, Fijan RS, in *Proceedings of the 9th Annual IEEE/EMBS Conference*, Boston, MA, 1987.

**3-D Gait: A Three-Dimensional Computer Graphic Display for Human Motion Analysis from TRACK Gait Data.** Lord PO, Bachelors Thesis, Massachusetts Institute of Technology, 1987.

**Comparison of Finite Helical Axis Estimation of Instantaneous Helical Axis from Noisy Kinematic Data.** Van der Meulen MC, Murphy MC, Mann RW, *Orthopaedic Research Society Conference*, Atlanta, GA, 1988.

**A Comparison of Smoothing Spine Algorithms for Obtaining Derivatives of Noisy Kinematic Data.** Murphy MC, Karlsson JOM, Mann RW, in *Proceedings of the 4th East Coast Clinical Gait Laboratories Conference*, Pennsylvania State University, University Park, PA, 36, 1988.

**Computer-Aided Surgery.** Cromie W, *The MIT Report*, The Massachusetts Institute of Technology Industrial Liaison Program, 1988.

**The Instantaneous Helical Axis and Its Application to Motion Analysis.** Karlsson JOM, Bachelors Thesis, Massachusetts Institute of Technology, 1988.

**Using Screw Theory to Analyze and Compare Kinematic Data.** Karlsson JOM, Murphy MC, Mann RW, in *Proceedings of the 4th East Coast Clinical Gait Laboratories Conference*, Pennsylvania State University, University Park, PA, 35, 1988.

**Automatic 6-DOF Kinematic Trajectory Acquisition and Analysis.** Antonsson EK, Mann RW, *J Dynamic Sys Meas Contr* 111, 1989.

**Real-Time Analysis and Display of Human Movement.** Lord PO, Masters Thesis, Massachusetts Institute of Technology, 1989.

**Human Analysis Movement—Opto-Electronics, LED Arrays, and Software Produce Rapid, Automatic, and Precise 3-D Position and Orientation Kinematics and Dynamics.** Rowell D, Mann RW, *SOMA: Eng Hum Body* (in press).

**Large Volume Close-Range Photogrammetric Data Acquisition with Direct Reduction to Rigid Body Orientation.** Mansfield PK, PhD Thesis, Massachusetts Institute of Technology (in press).



### [300] Computer Display of Musculoskeletal Anatomy

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The purpose of this project is to study the feasibility of using computer tomography (CT)-based images as a noninvasive method of obtaining patient-specific anatomical data. Patient-specific anatomical data are essential for: 1) accurate determination of the mass and inertial properties used in Newton's equation to calculate forces from accelerations; 2) specializing mathematically expressed, generalized musculoskeletal models to the particular patient's anatomy; and, 3) providing the surgeon, via computer graphics terminals, with realistic and accurate displays of relevant areas and volumes of the patient's anatomy. These capabilities are essential to the implementation of computer-aided surgical simulation beyond their intrinsic utilities to science and clinical practice.

**Progress**—We have demonstrated the feasibility and practicability of using CT or magnetic resonance imaging (MRI) data to automatically calculate the mass, mass center, and inertial tensor of body segments, by converting CT number and gray scale into local density or contouring the MRI images and assigning tissue density values. We are developing software algorithms to automatically extract from CT and MRI data, and store efficiently in computer memory, the geometrical information necessary to generate colorgraphic computer displays of aspects of patient's anatomy, i.e., the skeletal bones, joints, muscles, muscle insertions and origins, ligament insertions, and origins, etc.

We have demonstrated the ability to perform any of an infinite range of intertrochanteric osteotomies on a computer display of a three-dimensional femur defined from CT data. Our approach to this problem is fundamentally different from commercial firms developing similar anatomical display capability (CEMAX, PIXAR, SIEMENS) in that we must "do surgery" on the display, i.e., "cut" bones and "glue" them back together. Commercial firms are content to display the intact anatomy as is. Our approach makes very different

demands on the organization and display of the database representing the anatomical information. We have recorded our body segment parameter estimation software so that it may interface directly with our imaging software and the raw data from the imaging machines. For three-dimensional display and manipulation of anatomical material, we are employing both the more common "pixel" approach (using a Silicon Graphics Personal IRIS 4D20) and a volumetric "voxel" method (on a Sun 4/280S system equipped with Sun/TRANCEPT image generator). The two methods are complementary. The surface representation method allows fast manipulation of the anatomy, but requires considerable preparation of contours. The volumetric method requires little preprocessing but is computationally expensive and requires specialized image processing hardware. The volumetric representation is clearly superior for computation of mass/inertial properties of patient-specific body segments. Volumetric displays are particularly striking graphically and effective interactively. Starting with the external appearance of the body, software based on tissue densities can "strip off" the skin, then the subcutaneous tissue; muscle can then be removed, leaving the skeletal structure.

**Implications**—CT-based images of bone indicate high densities at ligament and tendon insertion sites; thus, noninvasive patient-specific determination of this data for musculoskeletal modeling appears feasible.

#### **Publications Resulting from This Research**

**Computer-Aided Surgery: An Interactive Simulation System for Intertrochanteric Osteotomy.** Chang GHP, Masters Thesis, Massachusetts Institute of Technology, 1987.

**Determination of Body Segment Inertial Properties.** Brown GA, Tello RJ, Rowell D, Mann RW, in *Proceedings of the 10th Annual RESNA Conference*, San Jose, CA, 817-819, 1987.

**Determination of Body Segment Parameters Using Computerized Tomography and Magnetic Resonance Imaging.** Brown GA, Masters Thesis, Massachusetts Institute of Technology, 1987.



**Determination of Body Segment Parameters Using Computerized Tomography and Magnetic Resonance Imaging.** Brown GA, Tello RJ, Rowell D, Mann RW, *ASME Winter Annual Meeting*, Boston, MA, 1987.

**Generation of Surface Anatomy from CT and MRI Images.** Tello RJ, Chang G, Mann RW, Rowell D, in *Proceedings of*

*the 10th Annual RESNA Conference*, San Jose, CA, 299-301, 1987.

**Automatic Three-Dimensional Mesh Generation of Skeletal Structures.** Levesque S, Masters Thesis, Massachusetts Institute of Technology, 1989.

### [301] Computer-Aided Surgical Simulation of Femoral and Tibial Osteotomy

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Our goal was to develop a computer-aided surgical simulation that would address design problems faced by physicians in orthopaedic surgical practice. In the hip joint, the degeneration of cartilage, synonymous with osteoarthritis, is usually focal and located on the superior region of the femoral head where it articulates with the acetabulum, the area loaded during the stance phase of normal level walking. In intertrochanteric osteotomy, the proximal section of the femur is transected and reoriented to move an area of good cartilage into the load-bearing region. The average 12-year life of total hip replacement has renewed interest in osteotomy since it is intrinsically conservative of joint tissue, compared with total replacement where the removal of much natural bone and the use of acrylic cement makes revision difficult. For the younger patient, a successful osteotomy can provide 5, 10 or more years of service before partial or total hip replacement are necessary. At the knee, proximal tibial osteotomy is indicated in patients with osteoarthritis of one tibiofemoral compartment producing varus or valgus deformity.

**Methodology**—The preoperative planning of either osteotomy procedure poses a substantial geometric and functional challenge to the orthopaedic surgeon. In current practice, planning is based on, at the most, biplanar X-rays of the affected region. Using a protractor, ruler, and grease pencil, the orthopaedic surgeon sketches on the two-dimensional X-rays a geometrical design of what is intrinsically a three-dimensional manipulation. In addition to the primary goal of cutting and

reconnecting the fragments of the proximal femur or tibia to bring good cartilage into proper load-bearing, the surgeon must also ascertain that the proposed alteration will cause minimal interference with the normal ranges of motion about the joint. Further, he/she must be confident that the alteration or reorientation of the bone components has not significantly lengthened or shortened the skeleton across the joint, considering also the possible alteration of the effective muscle or ligament lengths. Ultimately, the surgeon must be concerned with how the operation will affect, and hopefully improve, the mobility and grace of the subject in tasks such as normal level walking, stair-climbing, rising from a chair, etc. The magnitude and complexity of this design task undoubtedly explains, in part, the uncertain outcome of the procedure and represents a deterrence to more widespread practice of osteotomy.

Computer-Aided Surgical Simulation (CASS), addresses this surgical design problem as prototypical of many musculoskeletal alterations practiced in orthopaedic surgery. CASS borrows from the now well-established field of computer-aided design (CAD), adopting both commercially available computer hardware and graphic display terminals and reinterpreting and augmenting computer-aided design software.

Observation of surgeons and practice in orthopaedics suggests that the engineer-designer and the orthopaedic practitioner have much in common. They observe the circumstances of the situation and devise an idea for a solution. Whereas the engineer-designer now can carry out the exploration, itera-



tion, and optimization of design concepts in consort with the computer, the surgeon practitioner is constrained to a single solution, the particular surgical procedure performed in the operating room, and then must await the recovery of the patient to observe the consequences. Validation is uncertain since many procedures are very patient-specific. Even with similar procedures, the surgeon must follow a series of patients before evaluation of outcome is possible.

In some aspects, CASS is significantly different than CAD. Whereas the engineer designs *de novo*, the surgeon must deal *a priori* with the patient-specific, complex geometry of the relevant skeletal anatomy. The surgeon devises a plan to sever, realign, and reconnect these anatomical parts, then wants to explore the consequences of the changes, compared to the preoperative state of the patient. A further major distinction between the design engineer with a CAD system and a surgeon simulating a procedure on a patient's anatomy with the CASS system is the background and experience the respective operators bring to the computer system. The engineer is fluent in the geometric, mathematical, and physical implications of CAD manipulation and is familiar with computer hardware and software. The surgeon's relevant prior experience focuses on

direct observation and examination of the patient and studying the X-rays. Therefore, the computer's graphic display must present anatomy and mobility to the surgeon in a manner consistent with his prior experience; and the means by which the surgeon manipulates the display and interprets the consequences of the changes must be as traditional and easy to learn as possible.

**Implications**—Overall, CASS can be subdivided into three tasks: mobility analysis for presimulation recording and presentation of user-friendly, easily manipulable and interpretable dynamic displays of the patient's movement patterns; patient-specific anatomical representations for the computer displays on which the surgeon will simulate and evaluate the procedure and for the determination of body segment mass and inertial properties for dynamic analyses; and musculoskeletal modeling for the detailed mathematical representation of the skeletal, joint, muscle system for pre- and post-simulation evaluation. These tasks are described as separate projects.

#### **Publications Resulting from This Research**

**Computer-Aided Surgery.** Cromie W, *The MIT Report*, The MIT Industrial Liaison Program, 1988.

### **[302] Biomechanics of Shoulder Function and Crutch Walking**

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**Sponsor:** *The Royal Ottawa Health Care Group, The Royal Ottawa Hospital*

**Purpose**—The premise of this study is that undue stress and strain is placed on the structures about the shoulder during crutch walking which may lead to degenerative changes sooner than would normally be expected. The objective of the study is to perform the appropriate evaluation through physical examination and X-rays to determine shoulder anatomy, pathology, and function.

**Methodology**—Two groups of lower-extremity amputees will be utilized in the study. The first group will be those who have used forearm or auxiliary crutches for a considerable time during the period that they have been amputees. The second group of amputees (matching on age and level of amputation)

will have utilized crutches minimally during their period of amputation.

A full history, physical examination, and X-ray will be undertaken by the principal investigator. Reliability measures will be obtained by examination between the principal investigator and an investigator blind to patient history and level of dysfunction.

**Progress**—A literature review has nearly been completed. The formal project design and proposal can now be completed.

#### **Publications Resulting from This Research**

None reported.



### [303] Mechanical Factors in Ankle Sprain

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**Sponsor:** *Technion VPR Fund; Natovich Fund for Orthopaedic Research*

**Purpose**—While motion of the ankle joint has been studied in the past, the subtalar inversion-eversion motion has seldom been measured, despite its frequent involvement in everyday activity and in trauma such as ankle sprain, when the foot is forced into rapid inversion motion. In a previous study, we found that in unexpected and sudden inversion motion of the foot, the stretch reflex on the peroneal muscles remains unelicited for a period of approximately 70 ms from the onset of motion. In the present study, the dynamic properties of the human subtalar joint in sudden inversion were studied *in vivo* on a specially-designed apparatus. This type of motion is likely to occur in conditions of inversion sprain of the ankle joint. Therefore, it is important to quantify the kind of anatomical restraints involved in the joint. The purpose of this study was to measure these restraints.

**Methodology**—The human subtalar joint is modeled as a quasi-linear second order under-damped system to simulate sudden inversion motion of the subtalar joint. A special apparatus, consisting of a swiveling platform on which the tested leg and foot are positioned, and made to rotate at the level of the subtalar joint, was constructed for the measurements. The platform is driven by stretched linear springs with known stiffness to allow a rapid, complete trip (lasting less than 40 ms), and to ensure that during rotation the protective muscles are not activated by the stretch reflex. The swiveling platform is collaterally installed with a Kistler piezoelectric force platform, on which the other leg is made to stand in the same height as the tested leg, and by which weightbearing on the tested leg prior to and until the onset of the test can be controlled.

The kinematics of the swiveling platform is measured by means of a goniometer located at the axis. From the readings of a biaxial accelerometer attached to the platform, the angular acceleration, as well as the linear acceleration, components can be measured directly.

For each tested subject, the swiveling platform is unexpectedly released to rotate under the influence of the stretched springs. From the data obtained, the dynamic parameters of the subtalar joint, including stiffness, damping, inertia, and natural frequency are calculated.

**Results**—A total of 35 degrees inversion was produced on the tested leg rapidly enough (lasting less than 40 ms) to ensure that the protective muscles were not activated. The parameters of the joint were evaluated for 6 healthy subjects, and the following ranges were obtained at 35 degrees inversion: elastic stiffness 14-52 Nm rad<sup>-1</sup>, damping coefficient 1.4-2.9 Nms rad<sup>-1</sup> and natural frequency 78-125 Hz.

**Future Plans**—We plan to study the effect of the following parameters on the results obtained: amount of weightbearing on the tested leg; foot dominance; protective footwear; and the effect of ankle pathology on subjects with a known history of previous ankle sprains.

#### **Publications Resulting from This Research**

**Damping and Elastic Response of the Human Ankle to In Vivo Sudden Inversion Motion.** Mizrahi J, Ramot Y, Susak Z, in *Proceedings of IEEE Engineering in Medicine and Biology*, 629-630, New Orleans, LA, 1988.

### [304] Dynamic Estimation of Joint Loading

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Sponsor: *Whitaker Foundation*

**Purpose**—This project seeks a method of estimating joint loads in a multilink system. The estimation of joint loads involves the calculation of joint forces required to generate a given moment. Hence, the knee-joint forces generated in the process of gait can be estimated by accurate measurements of the motion of the foot and the shank and an estimate of the mass and inertial properties of these two segments.

**Progress**—A general system for dynamic estimation of joint loads in multilink systems is being developed. The project uses the WATRACK data-acquisition system in the Motion Analysis Laboratory for determination of link kinematics and estimates of the inertial properties of the link under study to calculate the joint loads required to generate a particular movement.

The first phase of this study involved the construction of a 2-degrees-of-freedom mechanical

pendulum. The axis of rotation of this system was equipped with a series of strain gauges to record directly the joint loads. These results will be compared to the estimates of the joint loads that are based on the WATRACK system. WATRACK uses the infrared light emitted by light-emitting diodes (LEDs) attached to the pendulum in a particular configuration called a segment. Based on recordings of the projected light from the diodes on 2 optoelectronic cameras, the spatial position of each LED is calculated. The system then calculates the full 6-degrees-of-freedom of the pendulum and uses the measurements of the inertial properties to calculate the joint loads. Therefore, a direct comparison of the measured and estimated joint forces will be possible.

#### **Publications Resulting from This Research**

None reported.

### [305] Stabilization of Thoracolumbar Injuries, Part I: Effectiveness of Orthotic Treatment

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Sponsor: *VA Rehabilitation Research and Development Service (Project #A509-RA)*

**Purpose**—Spinal orthoses have traditionally played an important role in the early mobilization of patients with thoracolumbar injuries. However, the treatment protocol for nonoperative, orthotic management of spinal fractures remains subjective due to a lack of objective data defining the three-dimensional (3-D) instability of spinal fractures and the extent to which different spinal orthoses can improve the biomechanical stability of the injured spine. The objective of this study is to evaluate the effectiveness of spinal orthoses in controlling the progression of deformities at the injured segments under the action of different loads and for different severity levels of injury.

**Methodology**—The methodology is demonstrated for a 3-point hyperextension orthosis. A 3-D finite element model (FEM) of the ligamentous spine with rib cage is used. An injury of increasing severity is simulated by progressively reducing the stiffness of T11-T12-L1 segments. Interaction of a 3-point hyperextension brace with the spine is simulated using experimentally measured stiffness properties of the brace. The model is used to predict displacements at the injured segment and loads exerted by the orthosis on the trunk. Arrays of force sensing resistor (FSR) transducers are used to measure loads at the orthosis-trunk interface while subjects perform different tasks.



**Preliminary Results**—Results for the hyperextension brace under gravitational and flexion loads are discussed. For injuries that cause up to 60 percent loss of segmental stiffness, the brace maintains angular displacements at the injured segment within the range of values of a normal unbraced spine. This holds true for gravitational and small flexion loads. However, under the action of a larger 10 Nm flexion moment, the kyphotic deformity in the braced spine exceeds the normal values at much less severe injuries. Preliminary results suggest that the effectiveness of brace treatment depends upon the segmental level of injury, severity of injury, and loads on the trunk caused by patient activities while wearing the brace.

Experimental work is underway to validate model predictions of orthotic loads for different tasks using normal subjects.

**Future Plans**—This project will investigate the biomechanical stability of spinal fractures stabilized with different spinal orthoses and surgical constructs, used alone or in combination. The response of an orthotically supported injured spine to loads in other planes, and evaluation of other orthotic designs such as the total contact molded plastic thoracolumbosacral orthoses (TLSO) will be investigated in the future. Further, experimental studies will be performed to measure changes in orthotic loads as subjects perform various tasks. The long-term goal is to develop objective treatment guidelines to adequately protect patients with spinal trauma during the healing process of spinal injuries, while preventing unnecessary surgery or bracing.

#### **Publications Resulting from This Research**

None reported.

### **[306] Stabilization of Thoracolumbar Injuries, Part 2: Effectiveness of Surgical Treatment**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A509-RA)*

**Purpose**—Surgical treatment protocol and the choice of the internal fixation system for thoracolumbar injuries remain subjective due to insufficient biomechanical data. The objective of this study is to measure the 3-D load-displacement behavior of injured segments before and after stabilization with different surgical constructs. The experimental injury models consist of burst fractures of L1 and L3 vertebrae and fracture dislocation of T12-L1 segment.

**Methodology**—Fresh human spines with intact bony and ligamentous structures will be used. In order to create the experimental burst fracture model, standardized stress risers will be created in the vertebral body (L1 or L3). The specimen will be subjected to an axial impact at its proximal end to produce a burst fracture. The fracture dislocation injury model will be created by combined application of flexion and torsional loads. The 3-D load-displacement

behavior of spinal segments will be measured using the WATSMART System with two cameras and infrared light-emitting diodes (LEDs).

**Progress**—We have developed and tested the method of experimentally creating a reproducible burst fracture in fresh human cadaveric spines. The experimental setup consists of a device to mount a multisegment spine specimen in a desired degree of flexion. A stress riser is created in the body of the L1 vertebra. A 30-pound mass is dropped on the specimen from a variable height to create the burst fracture at L1. The fracture is documented using computer tomography (CT) scans and closely resembles the burst fracture seen clinically. The optoelectronic method of measuring the 3-D motion at each motion segment of a multisegment spine specimen has been developed and tested for its accuracy and reproducibility. Three LEDs are attached to each vertebral body of interest via



threaded rods. Two infrared cameras locate the position of each LED in 3-D space at each instant in time. The motion of each vertebral body relative to the fixed (or anatomical) reference system can be calculated from the 3-D coordinates of the LEDs attached to the vertebral body. Thus, using this system and a specially designed loading frame, the 3-D load-displacement behavior of a multisegment spine specimen can be completely defined for loads applied in flexion, extension, lateral bending, and torsion. The motion measurement system was found to be accurate to within 0.5 degrees for angular displacements and 0.5 mm for translational displacements.

**Preliminary Results**—Using the methodology described above, we have tested three fresh human spine specimens (T11-L3) in the intact mode, following creation of L1 burst fracture, and after stabilization using two variable placement screw (VSP) spine plates with pedicular screws at T12, L1, and L2

levels. Preliminary results demonstrated significant reduction in the load-carrying capacity of the injured spine in flexion, lateral bending, and axial rotation. The VSP plates effectively immobilized the injured segments in flexion and restored the segmental stiffness to their pre-injury level in other modes.

**Future Plans**—During the next two years, we plan to quantify the 3-D nature of instability associated with the burst fractures and fracture dislocations of the thoracolumbar spine. Further, we will evaluate the 3-D stability of the appropriate surgical constructs used clinically in stabilizing these injuries. These data will provide a way of objectively comparing the efficacy of different surgical constructs in stabilizing different thoracolumbar injuries and understanding why some constructs fail.

#### **Publications Resulting from This Research**

None reported.

### **[307] Biomechanics of the Patellofemoral Joint: The Influence of Fixed Rotational Deformities of the Femur, In Vitro**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A474-RA, Part 1)

**Purpose**—The forces acting on the patellofemoral joint (PFJ) are considered to have strong correlation with patella disorders. Chondromalacia patella and subsequent osteoarthritis can result from abnormally high stresses on the articular surface of the PFJ. This is frequently due to the problems in the soft tissue or the tibia which have been well documented in the literature. However, the angular and torsional deformities of the femur may also result in high abnormal stresses in the PFJ. The specific objectives of this study were to determine the quantitative effects of fixed rotational deformities of the femur on PFJ contact pressures and the tension in the patella tendon.

**Methodology**—Seven fresh frozen human cadaver knee joints were used. The specimens were carefully dissected leaving only the femur, tibia, joint capsule, and the patella tendon. The proximal portion of the

patella was freed so that the pressure-sensitive film could be inserted through the superior part of the synovial pouch. The specimen was then clamped rigidly into steel cylinders in its anatomical position by aligning the cylinders along the axis of the proximal tibia and distal femur. The cylinders were then mounted onto a custom jig specifically built to be used in conjunction with an Instron machine. This system simulates fixed rotational deformities of the femur at various knee flexion angles and permits simultaneous measurement of the contact pressures in PFJ and the tension in the patella tendon. Once the specimen was securely mounted and positioned at a desired knee flexion, the neutral position of the PFJ was determined as the position that exhibited minimum tension in the patella tendon upon rotation of the femur. The intra-articular contact pressures were then measured using Fuji pressure-sensitive film (range: 0.2 to 2.0 MPa) that was cut to



5 × 5 cm and wrapped with thin polyethylene sheets for use in a fully-lubricated PFJ. The contact pressures were first measured in neutral position under 200 N of tension in the patella tendon.

For the contact pressures in rotated state, a new film was inserted and the tension in the patella tendon was maintained at 200 N for 20 minutes in neutral position before rotating the specimen. The internal and external rotation of 20 and 30 degrees was accomplished at 2 rpm using a motorized assembly built into the jig while the tension in the patella tendon was continuously monitored. The waiting period was standardized in order to minimize the viscoelastic effects of the tissue. For this study, the entire procedure was performed at knee flexion angles of 30, 60, 90, and 120 degrees. For all the tests, the initial relaxed tension in the patella tendon in neutral position was 200 N which was also used as the baseline data for normalization. In this manner, the true effect of rotational deformities of the femur on intra-articular contact pressures in the PFJ and the tension in the patella tendon could be studied.

**Results**—The fixed rotational deformities of the femur for seven fresh frozen human cadaver specimens resulted in nonlinear increase in intra-articular contact pressure on the contralateral facets of the patella. With the initial isometric tension of 200 N in the patella tendon for 30, 60, 90 and 120 degrees of knee flexion, the peak contact pressure showed no significant differences between the medial and lateral facets of the patella in its anatomical position ( $P > 0.5$ ). Upon 20 degrees of femur rotation, only a slight increase was noted for the tension in the patella tendon and the contact pressures in the contralateral facets of the patella. However, upon

30 degrees rotation, both the external and internal rotations of the distal femur resulted in significant increase in the tension of the patella tendon and the contact pressure on contralateral facets of the patella ( $P < 0.05$ ). For the contact pressures on the contralateral facets of the patella, the greatest increase was observed at 30 and 60 degrees of knee flexion for both the external and internal rotations of the femur which were  $28 \pm 3$  percent,  $22 \pm 4$  percent and  $31 \pm 4$  percent,  $24 \pm 3$  percent respectively. Further, the external rotation for all flexion angles showed a significantly higher peak contact pressure increase on the medial facet of the patella as compared to the internal rotation of the femur ( $P < 0.05$ ). The increase in the contact pressure on the retropatellar surface is thought to be one of the initiating factors for chondromalacia patella. Both the external and internal rotation of the femur resulted in an increase in tension in the patella tendon and in contact pressures on the contralateral facets of the patella. The fixed rotation of the femur with respect to the patella tendon showed an opposite effect as compared to the rotation of the tibia where pressure increases were noted on the ipsilateral facets of the patella. These findings provide baseline information regarding increased patella facet contact pressures that may be significant with chondromalacia and osteoarthritis due to fixed rotational deformities of the femur. Further, the surgical procedures aimed toward reducing contact pressures by performing osteotomies of the distal femur should only be performed after an accurate assessment of geometric parameters.

#### **Publications Resulting from This Research**

None reported.

### **[308] Biomechanical Evaluation of Canine Articular Cartilage of the Patellofemoral Joint: In Vivo Response to Fixed Rotational Deformities of the Femur**

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Sponsor: VA Rehabilitation Research and Development Service (Project #474-RA, Part 2)

**Purpose**—The forces acting on the patella are considered to have a strong correlation with patella disorders. It is believed that chondromalacia with its

subsequent osteoarthritis can result from high stresses on the articular surface of the patellofemoral joint. The abnormal stress distribution on



the articular surface of this joint is frequently caused by angular and torsional deformities of the femur. The objectives of this study are to determine how the fixed rotational deformity of the femur and the length of the diseased state correlate with subsequent osteoarthritis and chondromalacia in a canine model.

**Methodology**—The rotational deformities of the femur were surgically imposed on 12 skeletally mature mongrel dogs using 6-hole Dynamic Compression Plates (DCP). First, a lateral approach was used to perform the osteotomy of the femur. The femur was then rotated 30 degrees internally or externally and fixed with a 73 mm, 6-hole DCP. The animals were divided into 3- and 6-month groups with 6 dogs in each group. In each group, 3 dogs were subjected to 30 degrees of internal rotation of

the femur and the remaining 3 dogs of the group were subjected to 30 degrees of external rotation. All the procedures were performed bilaterally to insure even weightbearing. After sacrifice, the hind legs were disarticulated at the hip and the ankle joint. All the musculature, ligaments, and menisci were carefully dissected away to expose the articular surface of the patellofemoral joint for biomechanical evaluation.

**Preliminary Results**—Relaxed and unrelaxed shear modulus will be determined for each quadrant of the patella. Since the indentation tests are non-destructive, the specimens will also be evaluated both biochemically and histologically.

#### **Publications Resulting from This Research**

None reported.

## **C. Human Locomotion and Gait Training**

### **[309] Posture and Movement Stability**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B596-RA)

**Purpose**—Gait deterioration and postural instability are characteristics of aging that are poorly understood. Numerous identifiable and sometimes treatable diseases do affect mobility in the aged. Yet, the nearly ubiquitous gait deterioration does not seem to be part of another disease, nor has its pathologic basis been discerned. Falls are the most common cause of trauma and the largest single cause of all deaths of persons over the age of 74 years. The fractured hip is an obvious and all too commonplace reminder of falling for the aged.

Epidemiologic studies reveal an incidence of 7 hip fractures per 10,000 total population per year. The mean ages of these patients are 69 years for males and 73 years for females. Events such as these are not only painful and expensive, but they may also lead to a downhill course in the patient's overall physical and mental health. Miller (1978) found a

mortality rate of 27 percent 1 year post-fracture, as compared with 9 percent for an age-matched population. Senile gait disorder, the name often given to the advanced stage of this condition, may be the manifestation of deteriorating vision, proprioception, and musculoskeletal conditioning associated with the aging process. Despite the reversibility of some of these conditions, very little research has been conducted to study these systems as they relate to postural stability in the elderly. Recent developments in measuring postural instability, however, may offer promise toward understanding and treating this problem.

Postural sway can be measured by having subjects stand on an instrumented platform that accurately measures ground reaction forces and torques to the platform. These data may be graphically displayed to produce a two-dimensional repre-



sentation of the center of pressure of the feet as a function of time. These displays, called stabilograms, represent a record of postural sway.

A serious limitation to the present analysis of stabilograms is that they have not been approached from a motor control perspective. Efforts are underway at the NeuroMuscular Research Center to analyze stabilograms to determine if these data represent random process phenomena that can be modeled as Brownian motion within a boundary condition. Preliminary analysis of our model has yielded a simple technique whereby we can observe the role of the central nervous system in maintaining posture.

We propose to develop this technique further and apply it to the elderly population. In addition, we propose to: 1) identify the effect of visual input on postural stability; 2) investigate the hypothesis that peripheral neuropathy accompanying aging forms the basis of senile gait disorders; 3) develop treatment programs for senile gait disorders; 4) determine whether different movement strategies are

present that might explain why so many aged suffer falls during common activities such as stair-climbing or rising from a chair; and, 5) investigate common disabling foot disorders associated with aging to determine whether corrective methods improve postural stability during stance, gait, stair-climbing, and perturbation.

**Implications**—These studies will yield information that will enable us to develop a Postural Analysis System. The system will be comprised of a portable instrumented force platform and a computerized analysis procedure. The system will identify specific factors that contribute to the high incidence of falling and resultant trauma to the aged. It will also serve as a treatment outcome measure for the development of more effective rehabilitation programs to improve postural stability.

#### **Publications Resulting from This Research**

None reported.

### **[310] Microcomputer-Based Method for the Measurement of Spatial and Temporal Parameters of Gait**

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**Sponsor:** *Action Research for the Crippled Child*

**Purpose**—The purpose of this study is to develop a microcomputer-based method for the measurement of spatial and temporal parameters of gait.

**Methodology**—During swing phase, the instantaneous velocity of the forward-moving foot relative to the floor increases from zero at the instant of toe-off to a maximum, occurring about mid-swing, then decreases to zero once again when the foot contacts the floor at heel strike. The new apparatus measures the position of the foot at frequent intervals (256 per second) during the test walk and is thus able to construct a profile of the foot velocity for each foot and for each stride pair making up the complete walk. From this the computer derives: 1) left and right stride lengths; 2) left and right step lengths; 3) left and right stride times (equal to the

single support times for the contralateral foot); 4) double support times following left and right steps; 5) cadence; 6) walking velocity; and, 7) maximum foot velocities during each swing phase.

These are determined for the left and right foot for each stride pair. The averages and the ratios (left to right) of these averages is also calculated to demonstrate asymmetries.

The velocity diagrams are presented (on screen and in hard copy) since these are found to be excellent descriptors of the gait pattern.

No foot switches are used. Two punched paper tapes are attached, one to each foot, each carrying a continuous row of accurately positioned holes (10 per inch) and as the subject walks, these follow the feet, feeding out through two optical reading devices contained in a floor-mounted unit connected to the

microcomputer. The time and distance measurements are accomplished by counting and timing the passage of the punched holes.

There are no other attachments to the patient, the apparatus is unobtrusive and thus particularly suited to use with children. It is also portable, easy to use, low cost, and provides the results in simple tabular and graphical form, as a printed record, or the data may be stored in entirety on diskette for later retrieval and re-analysis.

**Results**—It has been used for some 36 months now in the study of aberrations of gait in neurologically-

deficient children as well as in adults. The results have been published.

#### **Publications Resulting from This Research**

**Assessment of Abnormalities of Gait in Children from Measurements of the Instantaneous Foot Velocity During the Swing Phase.** Law HT, Minns RA, *Child Care Health Dev* 13:311-327, 1987.

**Microcomputer-Based, Low Cost Method for Measurement of Spatial and Temporal Parameters of Gait.** Law HT, *J Biomed Eng* 9:115-120, 1987.

**A Low-Cost, Microcomputer-Based Method for Gait Measurement.** Wheelwright EF, *Semin Orthop* 4(2):88-89, 1989.

**Measurement of the Spatial and Temporal Parameters of Gait.** Law HT, Minns RA, *Physiotherapy* 75(2):81-84, 1989.

### **[311] Comparison of the Kinematic and Kinetic Components of Gait in Adult Males with Obesity and in Males of Normal Weight**

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**Sponsor:** *Foundation for Physical Therapy*

**Purpose**—The purpose of this study is to compare the kinematic and kinetic components of gait in adult obese males with those components in males of normal weight at a self-selected and a fast-paced walking speed. Although controversial, a relationship between obesity and the increasing prevalence of osteoarthritis (OA) has been demonstrated. Obesity may be a factor in the etiology of OA by mechanical means.

It has been demonstrated that pressure across weight-bearing joints is markedly elevated in the obese. Consequently, daily repetitive loading of the lower extremity joints in the obese during walking activity might generate forces great enough to cause mechanical wear and cartilage breakdown. Additionally, utilization of weight-bearing exercise in weight management might further exacerbate the wear.

**Progress**—One study has assessed temporal and kinematic elements of gait in the obese. None has

directly evaluated ground reaction forces or specific joint forces in the lower kinetic chain of the obese client. Thus, no quantitative information exists to support or refute the mechanical etiological theory of OA in the obese population.

An experimental set-up (pelvic soft-tissue restraints and foot, shank, and thigh segments) for monitoring the low-limb kinematics was designed and built. An instrumented mat for measurements of stride parameters was also designed and built.

Pilot studies of normal-weight subjects loaded with up to 50 percent body-weight are being conducted. With the completion of the mat, we will be able to use the WATRACK system to accurately document the time change of the lower-limb joints, overlaying gait-specific events such as heel touch-down, double and single support, and toe-off.

#### **Publications Resulting from This Research**

None reported.



### [312] Development of Normal Gait Patterns in Children: Creation of a Database

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**Sponsor:** *Hospital for Sick Children Foundation*

**Purpose**—The purpose of this study is to develop a normative database of gait patterns for children and adolescents. Specific goals are to further the understanding of normal gait development through careful documentation of locomotor performance in children and adolescents and to provide normal, age related, locomotor performance standards suitable for widespread use in clinical and research settings.

**Methodology**—The locomotor patterns of 100 healthy children will be measured in the Hugh MacMillan Medical Centre gait laboratory over a 2-year period. Ten children, preferably five females and five males, are being recruited in each of the following age groups: 1 to 2 years, 2 to 3 years, 3 to 4 years, 4 to 5 years, 5 to 6 years, 6 to 7 years, 7 to 8 years, 8 to 10 years, 11 to 14 years, and 15 to 18 years. A detailed medical history is taken of each potential subject in order to exclude children with any detectable neurological, musculoskeletal, or orthopedic abnormality. The gait assessments consist of 10 walking trials (5 for the left leg and 5 for the right leg). Lower limb kinematics are measured using the Vicon position detection system. Foot switches are used to measure the temporal factors of foot-floor contact. Ground reaction forces are measured using the Vicon position detection system.

Foot switches are used to measure the temporal factors of foot-floor contact. Ground reaction forces are measured with a force platform. The 3-dimensional kinematics, anthropometric, and ground reaction force information will be combined in an inverse dynamics analysis to determine joint reaction forces and net joint torques for the hip, knee, and ankle joints bilaterally. In addition, surface electromyography is being used to monitor hip and knee flexors and extensors, and ankle joint dorsi- and plantar-flexors.

**Progress**—Data collection has been underway for 1 year. Fifty-two subjects have been processed to date. Two age groups (8 to 10 and 11 to 14 years) have been fully processed to illustrate average joint angles, torques, and powers. These averages provide the initial information for the database of normal values. Analytical statistics that will be carried out include two-way analyses of variance (ANOVAs) for repeated measures to detect age and/or side related differences in the normalized locomotor profiles of the subjects.

#### **Publications Resulting from This Research**

None reported.

### [313] Development of a Posture Sensor and Evaluation System for Use in Gait Training of the Locomotion Disabled

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**Sponsor:** *Japanese Ministry of Education*

**Purpose**—In the locomotion-disabled person, such as paraplegic or hemiplegic patients with balance deficits, information about pelvic inclination is most useful from the rehabilitation point of view. In the present study, pelvic inclination and its time derivative in the sagittal and frontal plane, as well as in the

transversal plane during walking, are measured by the use of an inclinometer based on the gyroscope principle. This posture sensor system is used to evaluate gait and its improvement, if any, through rehabilitation.

**Methodology**—Inclinometer and angular rate sensors are put on the pelvis by belts for measurement of absolute angular displacement of the pelvis in sagittal and frontal planes, and measurement of angular rate in the transversal plane, respectively. Foot-switch sensors on the soles of the patient's shoes are used to detect plantar contact instants. The information is acquired and treated on-line in real-time by a 16-bit personal microcomputer via A/D converter.

**Progress**—Several software programs have been developed for measurement, data processing, and graphic presentation on-screen, and then tested on the normal subjects' walks as well as on patients having hip-joint disorders.

**Preliminary Results**—Preliminary experiments indicate that a graphic presentation shows basic characteristics of each patient's gait: for example, the walk of women who have osteoarthritis at the hip joint before and after surgical operation. Data acquired from normal subjects and patients have been charac-

terized by the proposed check points with regard to the waveform. It has been shown that these points can reveal the differences between them. Six features of a set of angular patterns were pointed out, and some were found to be invariant, while the rest vary, reflecting the degree of the disorder. Preliminary experimental results show the effectiveness of this system in the quantitative gait analysis and evaluation of the patient's progress in rehabilitation exercise.

**Future Plans/Implications**—We expect to develop an Expert System of analysis and evaluation of gait of each patient, for use in a rehabilitation program and for evaluation of its effects. This system is simple, compact, and especially suitable for clinical applications.

#### **Publications Resulting from This Research**

**Measuring System of Three-Dimensional Angular Displacement of Pelvis.** Ueda K, Irino T, Miyamoto H, Sakurai Y, Mori S, in *Proceedings, ICAART 88*, Montreal, 134-135, 1988.

### **[314] Fundamental Analysis of Postural Sway**

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**Sponsor:** *Liberty Mutual Insurance Company*

**Purpose**—This research seeks to explain the pattern of momentary displacements of a standing subject as observed in a stabilogram. The momentary movements of the center of pressure (COP) of a standing subject, as measured by a force platform, produce a trace called a stabilogram. This trace represents the output of a complex sensorimotor system aimed at maintaining erect posture of a human subject standing still.

**Progress**—A series of stabilogram studies were conducted on subjects of a young age group (20s and early 30s) and an older age group (70s). The subjects were asked to stand still for 15 seconds on a force plate and to look straight ahead. Force plate readings were collected at a high sampling rate.

**Results**—A statistical analysis of the momentary direction changes of the COP revealed that a simple stochastic model may explain the results. The model consists of an oscillatory mechanism that changes direction in a periodic manner contaminated by a Gaussian noise. Some of the results suggest that the relative magnitude of the noise increases with age. A new measure of the directionality in quiet standing is under consideration as a characterization of the overall stability of posture in quiet standing. The model is being considered as a possible tool to explain the pattern of momentary displacements, that is, to explain the element of "random motion" observed in stabilograms.

#### **Publications Resulting from This Research**

None reported.



### [315] Cognitive Control of Human Movement

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—This project seeks to intensify and expand basic research on the cognitive events that precede and allow the performance of voluntary movement. While applying research to the analysis of movement disorders, five projects will be pursued as follows:

*Planning of Aimed Hand Movements.* The aim of this new experimental procedure is to determine how people plan a series of aimed hand movements immediately after seeing a display specifying the targets to which movements must be aimed.

*Cognitive Control of Movement Sequences.* This project consists of two parts: 1) the three-dimensional analogue of the project discussed in the previous paragraph where the focus is on planning reaching and manipulation, both in normal and clinical (especially apraxic) populations; and, 2) analysis of two recently-discovered motor “illusions” that shed light on the mechanisms of serial ordering of behavior.

*Internal Representation of the Body Surface.* By having subjects perform a new speeded discrimi-

nation task in which all possible pairs of test sites serve as targets and distractors, the data can be analyzed with multidimensional scaling to allow for visualization of the body representation. Pilot work has turned up effects of handedness and posture.

*A Book.* A textbook, *Human Movement Control*, will be written. The book will provide an overview of research and treatment pertaining to each of the major activity systems including walking, looking, speaking, writing, reaching, and grasping.

*Cognitive Darwinism.* Darwin's theory of natural selection will be applied to cognitive function. The key notion is that spontaneous variation in cognitive structures may provide a basis for generalization, preparation, and other important phenomena.

#### **Publications Resulting from This Research**

None reported.

### [316] Biomechanics of Flat-Foot Running

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**Sponsor:** *NeuroMuscular Research Center*

**Purpose**—The anatomy of the foot has a significant role in determining the nature of the biomechanical dynamic interaction between the ground and the leg. Hence, it is conceivable that a common anomaly in foot anatomy would be manifested in a characteristic biomechanical pattern. The identification of such a pattern could serve as a measure of clinical severity and the efficacy of a suggested orthosis prescribed for treatment.

**Progress**—Using a force plate, a biomechanical study was performed to compare the ground reaction forces generated by a group of excessive

pronation (flat-footed) subjects and a control group. Individual patterns were studied for intrasubject and intersubject variability and for the existence of group-specific characteristics.

**Results**—Analysis of the results indicate that the force trajectories had small intrasubject variability, thus stressing the existence of individual “signatures” of ground reaction forces. The study further suggests that a portion of the medial lateral-force trajectory, when properly processed, is characteristic of the group.



The slope of that portion of the force trajectory was found to be twice as large for the control group as compared to the patient groups not wearing their prescribed orthoses. By selecting the maximum and minimum points of the medial-lateral interaction force corresponding to resupination and fitting those points to a function describing the dynamics of a foot-floor interaction, a spring recoil coefficient was calculated for pronated and normal arches.

This study found: 1) normal runners have approximately twice the spring coefficient of

pronated runners; 2) a pronator does not gain extra spring recoil in his arch by wearing an orthotic insert; and, 3) there is a linear relationship between a subject's resupination slope and the spring coefficient of his arch. Thus, it may be possible to use this as a biomechanical measure of flatfootedness or orthotic efficacy.

#### Publications Resulting from This Research

None reported.

### [317] Passive Dynamic Walking

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**Sponsor:** *Natural Sciences and Engineering Research Council; Centre for Systems Science, Simon Fraser University*

**Progress**—For the last two years, we have been studying the dynamics and control of bipedal walking and running. This work has been pursued with emphasis on legged machines, but the results also raise the possibility of substantial progress in rehabilitation. At first glance, one might think that such an apparently complicated activity as legged locomotion must be based on an elaborate pattern of control. However, we have found that human-like walking and running are actually natural limit cycles of simple mechanical bipeds. Thus these devices need no control at all; their motion is generated by an entirely passive interaction of gravity and inertia. Moreover, although bipeds are unstable while standing still, they turn out to be inherently stable while walking or running.

**Methodology**—The simplest example of this "passive dynamic" locomotion is provided by nothing more than a pair of straight legs connected by a pin joint. If placed on a shallow downhill slope and given appropriate initial conditions, such a mechanism will proceed to walk by itself. Analytical and experimental work on this straight-legged model was completed in 1988. Recently, we have calculated that the same effect works with knee-jointed legs, which produce a strikingly human-like gait. We plan to build an experimental knee-jointed walker in the near future.

Although the simplest of passive walkers use a downhill slope for energy supply, we have also

analyzed several other methods for "pumping" the passive cycle. These promise to allow dextrous and efficient walking over a range of slopes and speeds. Similar analyses have also been done for running. Walking has first priority for experimental work, and we are now completing a new straight-legged biped to test the "powered" walking model.

**Future Plans/Implications**—Later work will address locomotion on steeper slopes (>10 percent) than have been treated thus far, stair climbing, lateral balance (not an issue with our current two-dimensional models), and steering. In our view, the implication of this work for students of biomechanics and rehabilitation is that the mechanical structure of the body, rather than the neuromuscular system, is central to locomotion. This insight might be helpful for the design of leg prostheses. Perhaps for some patients just a simple brace would give the natural dynamics sufficient help so that they could take over on their own.

#### Publications Resulting from This Research

**Passive Bipedal Running.** McGeer T, *Centre for Systems Science, CSS-IS TR 89-02*, Burnaby, BC: Simon Fraser University, 1989.

**Powered Flight, Child's Play, Silly Wheels, and Walking Machines.** McGeer T, in *Proceedings of the IEEE International Conference on Robotics and Automation*, Scottsdale, AZ, 1592-1598, 1989.

**Passive Dynamic Walking.** McGeer T, *Int J Robotics Res* (in press).



## [318] Mechanics of Ankle-Foot Orthoses

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Sponsor: University of Akron

**Purposes**—Excess rotations at the ankle-foot complex present a major problem in the comprehensive rehabilitation of certain stroke patients with upper and lower motor lesions. These patients have uncontrolled muscle activity which may develop in to the “drop-foot” problem. Abnormal rotations also occur in the case of certain ligament injuries. Ankle-foot orthoses are generally prescribed to mitigate this problem. However, these orthoses have not been evaluated from a biomechanical viewpoint. The purpose of the present investigation is to study the biomechanics of ankle-foot orthoses.

**Progress**—We have developed two-dimensional finite element models of the ankle-foot-orthosis complex and studied various static and dynamic loading conditions. We compared stress and deformation patterns of the normal foot with those fitted with an orthosis.

In addition, we experimentally examined the strains developed in the orthosis in a walking cycle. Strain gauges were attached to polypropylene orthoses. The orthoses were fitted to normal test subjects and strains were recorded during the gait cycle. The orthosis was held in place with a strap anterior to the calf and a shoe which held the foot in the lower section. Principal strains were determined from three element Rosett gauges with assumed values for the material properties.

**Preliminary Results**—Peak stresses determined from both static and dynamic finite element models were similar in magnitude. Experimental results with

strain gauges were consistent with the results of finite element model simulation. Slight geometric modifications of the orthosis were made to eliminate stresses at undesirable points. These design modifications allow functional plantar flexion, reduce instability at the subtalar joint, and facilitate heel-to-toe gait pattern.

**Future Plans/Implications**—While the present simple two-dimensional analyses demonstrate the feasibility of using finite element models for redesigning the ankle-foot orthoses, further examination of dynamic conditions and more complex three-dimensional (3-D) dynamic finite element calculations are needed to be able to predict the total response of the ankle-foot orthosis system.

We are developing those 3-D finite element models of ankle-foot-orthosis systems. In addition, we propose to test-fit the orthoses to human subjects and examine the effect of these orthoses on knee, ankle, and subtalar joints. Also, we plan to verify the results of the 3-D finite element model with experimental stress analysis of these orthoses. This would provide a comprehensive biomechanical understanding of the ankle-foot-orthosis systems.

### Publications Resulting from This Research

**One More Step in Redesigning the Ankle-Foot Orthotic.** Lam PC, Downing M, Reddy NP, *SOMA: Eng Hum Body* 2(1):36-39, 1987.

**Stress Analysis of Ankle Foot Orthoses.** Reddy NP, Yanke M, Lam PC, in *Proceedings of the American Society of Biomechanics Conference*, Davis, CA, 1987.



### [319] Development of a Sensory Substitution System for the Insensate Foot

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Sponsor: VA Rehabilitation Research and Development Service (Project #A383-DA, Part 1)

**Purpose**—Our goal was to develop a reliable, cost-effective foot sensory substitution prototype device. This has been accomplished.

**Methodology**—Our system allows the long-term recording of pressure-time data during ambulation for each step from 14 pressure sensors located within the insoles. The recorded pressure data are fed back to the subjects through electrotactile stimulation. The insole data-acquisition system is portable, battery-supplied, and book-sized. It consumes 19 mW at a clock frequency of 6 MHz by providing a SLEEP mode and a SYSTEM STOP mode. The HD64180 microprocessor has the capacity of 512-kbyte physical memory. This system can collect pressure data from 14 channels at a 35-Hz sample frequency for 5 seconds every minute over a 2-hour period. It can also continuously collect pressure data for 15 minutes. After the test, it downloads the data to the IBM PC, which translates the voltages into pressures by looking up prestored calibration tables.

**Results**—We have written extensive software for: 1) displaying the data as pressure versus time; 2) determining the integrated area under the pressure curve versus time; 3) determining the averaged peak pressures versus time; 4) determining and displaying heelstrike-to-toeoff versus time; 5) determining foot contact duration under each sensor for each step versus time; 6) determining and displaying center-of-pressure versus time for both feet; and, 7) determining and displaying the variation of y-coordinate of capillary osmotic pressure (COP) versus time.

We designed and developed a portable electrotactile stimulator for sensory feedback. The stimulator has 14 inputs from the insole sensors and 14 corresponding electrodes on a belt around the waist for stimulation. It can be used alone or in conjunction with our portable data-acquisition system for feedbacking the processed data. It can be used for a mobility aid for the blind subjects.

We have been using the system clinically by collecting pressure data through the portable unit from 17 sensate and 3 insensate subjects for 4 minutes of continuous walking during multiple trials (60 sensate, 40 insensate). We are also examining data obtained during the fatigue of a 2-hour walk from 7 normal subjects to find how normals vary pressure distribution under the foot over time. This initial preliminary clinical data does not reveal a simple peak pressure pattern of protective gait modification. Compared with those from normal subjects, the peak pressures from the matched insensate are not much higher. We have studied pressure-time integrals under pressure curve and foot contact durations for each sensor.

**Future Plans**—The sensory substitution system for the insensate foot has been completed. We plan to explore and identify those metrics that are significant discriminators between sensate and insensate gait. We will evaluate the sensory substitution system as a blind mobility aide and look for other parameters in addition to peak pressures as discriminators.

#### Publications Resulting from This Research

- Pressure Monitoring Under Insensate Feet.** Maalej N, Zhu H, Webster JG, Tompkins WJ, Wertsch JJ, Bach-y-Rita P, in *Proceedings of the IEEE Engineering in Medicine and Biology Society*, 1823-1824, 1987.
- Capacitive Sensors for Measuring the Pressure Between the Foot and Shoe.** Kothari M, Webster JG, Tompkins WJ, Wertsch JJ, Bach-y-Rita P, in *Proceedings of the IEEE Engineering in Medicine and Biology Society*, 805-806, 1988.
- A Conductive Polymer Pressure Sensor.** Maalej N, Bhat S, Zhu H, Webster JG, Tompkins WJ, Wertsch JJ, Bach-y-Rita P, in *Proceedings of the IEEE Engineering in Medicine and Biology Society*, 770-771, 1988.
- A Microprocessor-Based Data-Acquisition System for Monitoring Foot Pressures.** Zhu H, Maalej N, Webster JG, Tompkins WJ, Bach-y-Rita P, Wertsch JJ, in *Proceedings of the IEEE Engineering in Medicine and Biology Society*, 1599-1600, 1988.
- A Capacitance Pressure Sensor Using A Phase-Locked Loop.** Patel A, Kothari M, Webster JG, Tompkins WJ, Wertsch JJ, *J Rehabil Res Dev* 26(2):55-62, 1989.



## [320] Foot Pressure Distribution During Walking and Shuffling

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Marquette University, Milwaukee, WI 53233

Sponsor: VA Rehabilitation Research and Development Service (Project #A383-DA, Part 2)

**Purpose**—The purpose of this project is to quantitatively study and compare plantar pressure distributions during normal walking and shuffling gait.

**Methodology**—We are using insoles, each instrumented with 7 pressure sensors and a portable microprocessor-based data acquisition system, for data collection. The sample frequency is 20 samples per second for each channel. Seven sensors are located under the posterior heel, anterior heel, first metatarsal head, second metatarsal head, fourth metatarsal head, fifth metatarsal head, and the hallux. To date, foot pressures have been recorded from 10 normal subjects during 4 minutes of continuous walking and shuffling at metronome-controlled cadences (105 steps/min for walking and 104.8 steps/min for shuffling).

**Results**—Preliminary results include data collected from 10 normal subjects who were tested for 4 minutes of continuous walking and shuffling. In this group, normal walking is statistically more consistent than shuffling gait in terms of peak pressure, pressure-time integral, and foot contact duration. It has also been found that data differ between walking and shuffling (peak pressure, pressure-time integral, and foot contact duration). Statistically, the differences between walking and shuffling in terms of foot-contact duration and peak pressure are larger than those for pressure-time integral. Peak pressures are decreased and foot contact durations are increased at all sites during shuffling.

### Publications Resulting from This Research

None reported.

## [321] Metatarsal Head Movement and Discrete Plantar Sensors

Jacqueline J. Wertsch, MD; Melvin B. Price, DPM, PT; Alvin R. Smith, DPM; Jay Loftsgaarden, BS;  
Hongsheng Zhu, MS; Gerald F. Harris, PhD, PE

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Sponsor: VA Rehabilitation Research and Development Service (Project #A383-DA, Part 3)

**Purpose**—It is well known that during stance phase the foot pronates. During pronation there is a first ray dorsiflexion and inversion along with lesser metatarsal dorsiflexion and eversion. Thus, there is a theoretical elongation of the foot with pronation and shortening with supination. These biomechanical considerations raise concern about the proper placement of discrete plantar sensors to measure normal pressure under the metatarsal heads.

**Progress/Methodology**—To study the metatarsal head movement during stance phase, we placed radiopaque markers beneath the first and fifth metatarsal heads as identified by palpation during

non-weightbearing. Markers were also placed at the tip of the great toe and posterior aspect of the calcaneus. The feet were X-rayed (AP and lateral) during both stance and non-weightbearing. As the subject ambulated over the Alimed foot imprinter, weightbearing areas were identified to determine the site for discrete sensor placement. The data collected from these sites was analyzed for repeatability from trial to trial. Also, a 4×4 array of 5 mm Interlink conductive polymer sensors was used under the second metatarsal head to estimate maximal metatarsal head movement in the anteroposterior (AP) direction as well as transverse plane. A center of pressure algorithm will be used to monitor any change in pressure distribution under the second

metatarsal head throughout stance phase for each step during multiple trials.

**Preliminary Results**—With the X-ray technique, we studied 3 subjects with varying foot types (flexible flatfoot, cavus foot). All showed less than a millimeter of perceivable displacement of the metatarsal heads with no discernable difference between the first and fifth metatarsal heads. The repeatability of the sensor data from the discrete site chosen by the footprint was analyzed statistically. Over 80 steps per subject, from various trials, were analyzed for repeatability for a total of 10 normal subjects. There was 93 percent repeatability for peak pressure during normal walking. This suggests that any

possible small position changes of the insole from day to day with respect to the bony structure of the foot were not significant.

**Future Plans/Implications**—The conductive polymer pressure sensor array study is in progress. Our clinical footprint and X-ray studies suggest that discrete plantar sensor placement based on dynamic footprint techniques and biomechanical exam of the foot is practical and gives reproducible data trial to trial.

#### **Publications Resulting from This Research**

None reported.

### **[322] Use of an Insole Sensor System with Cane Walking**

Jacqueline J. Wertsch, MD; Jay Loftsgaarden, BS; Gerald F. Harris, PhD; Hongsheng Zhu, MS; Jeffrey Harris, BS; Melvin B. Price, DPM, PT

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A383-DA, Part 4)

**Purpose**—The objective of this study is to determine the effect of using a cane in the ipsilateral (IP) versus contralateral (C) hand when trying to unload a foot.

**Methodology**—This study utilizes an insole sensor system which measures pressures at 7 sites on the soles of both feet over extended recording times. The insole data-acquisition system is portable, battery-supplied, and book-sized. This system can collect pressure data from 14 channels at a 35-Hz sample frequency. After the test it downloads the data to the IBM PC, which translates the voltages into pressures with the use of prestored calibration tables.

**Progress**—Subjects consist of volunteers taken from a pool of healthy physicians, professors, and medical and graduate students. Imprints of the feet of each subject are made using an Apex Foot Imprinter. A dynamic image is obtained by having the subject walk on the pad barefoot during normal walking. The same procedure is repeated two addi-

tional times on each foot for a total of three dynamic images in order to obtain a measure of consistency. Using this method, the high pressure points are located for the sensor placements. To date, 9 normal subjects (over 2,400 steps total) have been assessed with both IP and C cane use. Integrated pressure-time data ( $\text{kPa} \times \text{sec}$ ) for each sensor has been collected.

**Results**—Analysis of initial data indicates an average decrease of 21.5 percent when the cane is used in the contralateral hand versus unassisted gait. Use of a cane in the ipsilateral hand unloads an average of 17.0 percent, but also yields a slight increase in pressures (9.1 percent) in the uninvolved foot, which is not seen with contralateral cane use. This increase in loading on the uninvolved foot is causing concern and further studies are in progress to analyze this phenomenon.

#### **Publications Resulting from This Research**

None reported.



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**[323] Crutch Walking Analysis with a Portable DAC System**

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**Jacqueline J. Wertsch, MD; Gerald F. Harris, PhD, PE; Hongsheng Zhu, MS; Jay Loftsgaarden, BS; Melvin B. Price, DPM, PT**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A383-DA, Part 5)*

**Purpose**—The objective of this study is to investigate the effect of ipsilateral (IP) versus contralateral (C) crutch usage upon selected (discrete) plantar pressure patterns.

**Methodology**—A portable, microprocessor-based data acquisition system is being used to quantify plantar pressure distribution during assisted (crutch) and unassisted gait. The portable system is used to collect pressure data from 7 sites beneath the plantar surface of each foot at a rate of 20 samples per second. Subsequent to acquisition, data is uploaded to a microcomputer for processing and analysis.

**Progress**—Four voluntary subjects have received custom sensor insoles for inclusion in the study. Sensors are located beneath high load points of each

foot based upon dynamic images obtained with the use of an APEX foot imprinter. Plantar loading data has been acquired for each of the 4 subjects during unassisted, IP crutch-assisted, and C crutch-assisted ambulation.

**Results/Future Plans**—Several key metrics indicating statistical utility in discriminating pressure patterns have been identified in the preliminary study. Metric identification and parametric analysis will continue as the study population is expanded. Future plans include an increased study population and examination of several different crutch types.

**Publications Resulting from This Research**

None reported.

# X. Ulcers/Wounds

*For additional information on topics related to this category see the following Progress Reports: [2], [3], [60].*

## A. Pressure Sores

### [324] Bedsore Biomechanics

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**Sponsor:** *Edwin Shaw Hospital; The University of Akron*

**Purpose**—Bedsore (pressure sores) or decubitus ulcers are localized areas of cellular necrosis resulting from prolonged excessive stresses on soft tissues. They present a major problem in the comprehensive rehabilitation of spinal cord injured patients and others with paralyzing neurological diseases. The type and magnitude of stresses generated in the tissue depend on body build, mechanical properties of the tissue, mechanical properties of the cushion, and posture, etc.

The objectives of this investigation are 1) to study the stress distributions developed in the tissue in individuals with various types of body build; and, 2) to develop and evaluate interface pressure transducers for measuring tissue-cushion interface pressure.

**Progress**—Decubitus ulcers usually occur around bony prominences. A frequent site of ulcer formation is the soft tissues of the buttock. We have developed two types of 2-D physical models of the buttock. In each of these models, PVC gel simulating the soft tissue was cast around a wooden core simulating the bone. The first model had a rounded edge core to simulate blunt bony prominence. The second model consisted of a flat circular (sharp) edge "bone" core to simulate sharp bony prominences.

Each of these models was placed on a representative cushion and loaded. A grid etched on the

"soft tissue" model allowed photography for calculating strains and stresses in the tissue. Cushion materials were compared in terms of the tissue-cushion interface pressure and shear stresses generated in the soft tissue.

In addition, we are developing interface pressure transducers using conductive polymers. We are in the process of evaluating various types of polymers for suitability as interface pressure transducers.

**Preliminary Results**—Shear stresses generated in the soft tissue model were significantly larger in magnitude in the case of sharp bone core when compared to the rounded edge model. However, the compressive stresses in the sharp edge case were lower than the rounded edge model. There were significant stress concentrations in the case of the sharp edge model. Gel cushion performed better when loaded at a 30 degree inclination when compared to the foam. By comparison, foam cushions performed better under vertical loading.

**Implications/Future Plans**—Our preliminary results suggest that no single type of cushion can be used for the bedsore problem. There is a need to develop a composite cushion which incorporates the properties of foam (good enveloping and reduced compressive stresses) and gel (good at reducing interface and internal shear in horizontal loading).



Our studies suggest that inclined loading (backward or forward tilting) is dangerous to lean individuals, and advantageous to fat individuals. Various other types of geometries and cushion combinations should be investigated.

Three-dimensional models that feature more realistic mechanical and rheological properties are necessary. Finite element models are needed to incorporate a variety of geometries and tissue properties. We are pursuing such studies.

Recent improvements in conductive polymers offer a unique tool for developing thin, flexible

pressure transducers for continuous monitoring of cushion tissue interface pressure.

### Publications Resulting from This Research

**Bedsore Mechanics.** Reddy NP, Candadai R, in *Sixth Southern Biomedical Engineering Conference: Digest of Papers*, 55-58, 1987.

**Stress Analysis of Cushion Supported Tissues with Respect to the Bedsore Problem.** Candadai RS, Reddy NP, Joshi AM, 1988 *Advances in Bioengineering*, New York: American Society of Mechanical Engineers, 1988.

**Stress Analysis of Cushion Supported Tissues with Respect to the Bedsore Problem.** Candadai RS, Masters Thesis, University of Akron, 1989.

## [325] An Ultrasonic Technique to Noninvasively Measure the Stiffness of Soft Tissue

**Thomas A. Krouskop, PE, PhD; Patricia A. Barry, MS; Don J. Winningham; Pushkin Kachroo**  
The Institute for Rehabilitation and Research, Houston, TX 77030

**Sponsor:** *Mobility Foundation*

**Purpose**—Pressure sores are a serious medical problem for a patient confined to a bed or wheelchair. Treatment of pressure sores is time consuming and difficult. A clinically viable method of identifying tissue damage before the sore is visually apparent could make treatment more effective and accelerate the healing process. The sensing system being developed in this project may also be of use in monitoring the recovery process after tissue is damaged by mechanical loadings.

The method developed measures the stiffness of tissue near the skin surface. With this method, it should become possible to identify pressure sores by a change in tissue stiffness, before they are visible at the skin surface. By this method, a disk vibrates against the skin while an ultrasound beam measures the amplitude of the perturbation as it propagates through the tissue. The pattern of propagation indicates the stiffness of the tissue. At this time the sensitivity of the method has been established and the ability to detect slight changes in tissue stiffness has been demonstrated. However, further development is necessary to permit the procedure to reliably identify damaged tissue before it is detectable using conventional clinic tools.

**Methodology**—The ultrasound measuring system consists of a vibrating head with an ultrasound

transducer mounted in it. It vibrates with a stroke of 3 mm at a frequency of 8 Hz. The ultrasound is focused on depths up to 4 cm with a precision of 0.015 cm. It tracks the displacement of the tissue at that depth. The computer samples the displacement and calculates the peak-to-peak amplitude to motion. Depth versus amplitude is plotted to give a visual understanding of the results. The data is segmented and fit to a series of curves. A Young's modulus is then calculated for each curve to characterize the stiffness of the tissue in the region.

**Progress**—The instrument has been built and tested. Data taken with the machine are consistent and sensitive to changes in stiffness. Two studies have been done. A repeatability study shows that data taken from the same anatomical location over several days are the same within the error limits of the instrument. A tissue identification study shows that similar tissue in different subjects have similar stiffness.

**Preliminary Results**—This instrument provides quantitative mechanical information about the tissue it surveys. It is possible to differentiate between blood vessels, bones, and muscle tissue. An experienced user is able to identify pressure sores and other anomalies using an interactive computer algo-

rhythm. The system is restricted to tissues close to the skin as the data become unreliable beyond depths of 2.5 cm or near the bone. The area of interest in this study is typically underlying in the range of 0.1 cm through 1.5 cm depth.

It has been shown that the curves characterizing the tissue are similar for the same anatomical site over a period of several days. Slight variations are caused by shifts in the preloading caused by the perturbator head. Tissues have similar characteristics in different subjects.

**Future Plans**—Studies of bruised tissue and stage 1 pressure sores are planned. With data from these

studies it should be possible to develop guidelines for identifying tissues at risk of breaking down. While many data are provided by the perturbator, it is necessary to decide which data provide the best information for diagnosing pressure sores and how to present it for clinical use. Finally, the procedure will be tested for its accuracy in locating pressure sores.

#### **Publications Resulting from This Research**

None reported.

### **[326] Lysyl Hydroxylase Activity: Relationship to Skin Collagen Metabolism in Spinal Cord Injury**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research (Mary E. Switzer Research Fellowship)*

**Purpose**—Chantraine (1978) demonstrated under-hydroxylation of both proline and lysine in bone collagen below the level of injury in spinal cord injury (SCI) patients. Hydroxylysine is one of the amino acids involved in forming inter- and intramolecular crosslinks, a factor determining the great tensile strength of the collagen fibrils. Hydroxyproline is essential in maintaining the integrity of the collagen helix and provides thermal stability to the collagen fiber. These findings suggest the possibility of a similar deficiency in the skin of SCI patients. We are investigating the possibility by obtaining skin biopsies above and below the level of injury in patients admitted to The Institute for Rehabilitation and Research for surgical repair of skin ulcers.

**Methodology/Results**—We have obtained skin biopsies from nonparalyzed patients. The activity of the enzyme lysyl hydroxylase is approximately the same in control skin and skin from above the injury, but

it is much lower in skin from below the injury. We have measured the concentration of four characteristic collagen amino acids in a small number of biopsies: Pro, Hyp, Lys, and Hyl. The percent hydroxylation of Pro is lower below the level of injury than above, but the percent hydroxylation of Lys is unchanged.

**Implications**—We are seeking funding to extend this project to include biopsies on patients who have never had decubitus ulcers. It is important to establish whether there are structural differences in the skin collagen of patients that have decubitus ulcers compared to patients that have never had them.

#### **Publications Resulting from This Research**

**Biochemical Changes in Skin Composition in Spinal Cord Injury: A Possible Contribution to Decubitus Ulcers.**  
Rodriguez GP, Claus-Walker J, *Paraplegia* 26:302-309, 1988.



### [327] Identification and Evaluation of a Comprehensive Skin Care Program to Prevent Skin Breakdown in Spinal Cord Injured Patients

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The Virginia Regional Spinal Cord Injury Center, Department of Orthopaedics, University of Virginia Medical Center, Charlottesville, VA 22908

Sponsor: National Institute on Disability and Rehabilitation Research

**Purpose**—The purposes of this study are to identify and evaluate a comprehensive skin care education program to prevent recurrent skin breakdown in patients with spinal cord injuries, and evaluate two methods of gaining the subjects' cooperation in practicing skin protection behaviors (subjects in Group I received a behavioral intervention while those in Group II received a psychological intervention).

**Progress**—Follow-up data were obtained by telephone, mail, personal interviews, and hospital records. Of the 24 subjects who have completed the program, 8 (33 percent) have been readmitted for skin problems. Time since discharge ranges from 3 to 30 months.

**Preliminary Results**—Subjects who were readmitted because of pressure sores were compared with those who were not, based on the following variables:

demographic, medical, psychological, cognitive, treatment group, and skin care knowledge. Those who were readmitted had scores which indicated greater cognitive deficits on the WAIS-R Vocabulary test and the Neurobehavioral Rating Scale ( $t = 2.16$ ,  $p < 0.05$ ;  $t = 2.28$ ,  $p < 0.05$  respectively). In addition, subjects who were readmitted had lower scores on the skin care knowledge test at discharge ( $t = 2.17$ ,  $p < 0.05$ ). Fewer subjects receiving the behavioral intervention were readmitted, but the difference was not statistically significant.

**Future Plans**—The current award will terminate in September 1990. These preliminary results will be reevaluated as more subjects are added to the study, and as follow-up data continue to be collected.

#### Publications Resulting from This Research

None reported.

### [328] Treatment of Pressure Ulcers

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Sponsor: National Institute on Disability and Rehabilitation Research

**Purpose**—Development of improved clinical protocols may help reduce the staggering morbidity statistics resulting from pressure ulcers in people with spinal cord injury (SCI). In order to develop optimal active treatment protocols for pressure ulcers, basic wound-healing research is essential. The objectives of this study are to: 1) determine, in cell culture, the optimal concentration of oxygen and optimal pressure for fibroblast activation and macrophage deactivation; 2) determine, in cell culture, the optimal dosage of growth factors to stimulate fibroblast activation; 3) determine, in rabbits, optimal use of oxygen for healing of both

subcutaneous porous implants and full-thickness skin defects; 4) determine, in rabbits, the optimal dosage, timing, and type of growth factor drug delivery for healing of both subcutaneous porous implants and full-thickness skin defects; 5) test, in pigs and dogs, the optimal oxygen therapy in combination with the optimal growth factor delivery systems (determined in rabbits) for subcutaneous implants, full-thickness skin grafts, and full-thickness skin defects; and, 6) evaluate the efficacy of various therapeutic approaches on pressure ulcers in patients with SCI.



**Methodology**—The optimal concentration of oxygen and optimal pressure for fibroblast activation, epithelial activation, and macrophage deactivation will be determined by growing cells in a controlled environment at various predetermined combinations. The activation of cells will be determined by analysis of cellular metabolism, production of collagen, (fibroblast) and cell growth. The optimal concentration of platelet-derived growth factor for cellular activation and deactivation will be determined by *in vitro* tests of cellular metabolism and cell growth. Growth factors exhibiting the greatest potential will be used in combination *in vitro* to determine if additional increases in cellular metabolism and growth can be obtained from combining growth factors. The growth factors exhibiting the greatest potential will be attached to Dacron and collagen matrices by the Vitaphore Corporation. The release rates of the growth factors will then be determined by *in vitro* testing. The matrices will be

tested in cell culture to determine the load of growth factor necessary to elicit increased cellular metabolism, collagen production, and cell growth.

**Preliminary Results**—Tests of the concentration of oxygen and duration for fibroblast activation are in progress. Preliminary results suggest that high levels of oxygen (50 percent, 65.5 percent, and 85 percent) for long periods (>6 hours) cause decreased proliferation. Tests of the concentration of oxygen and duration for macrophage deactivation have started as have tests of the ability of platelet-derived growth factor to increase activity of fibroblasts.

**Future Plans**—*In vitro* testing will continue and *in vivo* testing will be initiated during the next 2 years of this 5-year project.

**Publications Resulting from This Research**  
None reported.

### [329] An Analytical Service Demonstration of the Role of Biochemical and Behavioral Indicators in the Prevention of Recurrent Pressure Sores

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Sponsor: National Institute on Disability and Rehabilitation Research

**Purpose**—Our purpose is to confirm the potentiality of a biochemical indicator to predict skin breakdown and the efficacy of specific self-directed behaviors to prevent recurrent pressure sores.

**Methodology**—This is an observational, prospective, cohort study. Spinal cord injury persons are randomly assigned to two groups. The control group will be interviewed only at the beginning and at the end of the study, and will provide a 24-hour urine sample at each of those times. The experimental group will initially be interviewed in person, and then by telephone every 4 to 6 weeks. They will provide a 24-hour urine sample at the time of each interview. Follow-up will continue for 2 years, or until the subject develops a pressure sore, whichever comes first.

The interviews will elicit demographic information, medical history (with special emphasis on

incidence of pressure sores), and a description of the usual skin care regimen. The urine will be assayed for the content of glucosyl-galactosyl hydroxylysine, a collagen metabolite.

The data analysis will seek to establish the relative risk of developing a pressure sore based on the fluctuations in urinary concentration of the collagen metabolite and/or specific items in the skin care regimen.

**Progress**—Recruitment of subjects is almost finished. Compliance has been extremely good. Three patients have developed pressure sores. Some behavior patterns are beginning to emerge.

**Implications**—Successful completion of this research project will provide a means of identifying patients at imminent risk of developing pressure sores. More aggressive preventative measures can then be



brought into play to forestall an actual skin breakdown. This should translate into a considerable reduction of hospitalization time and costs.

#### Publications Resulting from This Research

None reported.

### [330] Therapeutic Intervention for Healing Pressure Sores with Electrical Stimulation on Persons with Spinal Discontinuities

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**Sponsor:** National Institute for Disability and Rehabilitation Research; Research Communities of Slovenia, Ljubljana, Yugoslavia

**Purpose**—The purpose of this project is to conduct a carefully controlled and quantified study on the effects of subthreshold tetanizing and DC currents on wound healing. Pressure sores in patients with spinal discontinuities and wounds due to peripheral vascular diseases are included in the study.

**Progress**—The data obtained under the same protocol are being collected from several centers and being stored with the generated database (using D-base IIIpl) system. A logic model was developed to analyze the role of various parameters regarding wound healing. The healing process was described by decision rules using the assistant inductive learning system. Based on already completed cases, predicted values of time constants of the healing process were obtained which were significantly shorter for wounds treated by electrical stimulation (ES).

As the evidence for the clinical effects of es has been growing, we are focusing our efforts on searching the mechanisms by which electrical currents influence healing. The endogenous potentials of injured skin were measured and found to be significantly higher (more positive) compared to the intact skin. Since the temperature increase due to ES is expected, a thermographic method for registration of thermal conditions of the wound and surrounding skin is being developed and applied. The flow speed of erythrocytes has been examined by using capillary microscopy. Bacterial analysis of samples taken from the wound has also been done.

**Results**—Using the existing findings as well as our latest results, a hypothetical model for possible mechanisms of ES effects on living systems based on the self-organization theory has been developed.

#### Publications Resulting from This Research

**Analysis of Changes of Thermal Conditions in Wounds Due to Electrical Stimulation.** Likar B, Rencel S, Presern-Strukelj M, Erjavec T, Klesnik M, presented at *Bioelectric Repair and Growth Society (BRAGS)*, Cleveland, OH, 1989.

**Clinical Experiences in Wound Healing by Electrical Stimulation in SCI Patients.** Savrin R, Benko H, Stefanovska A, Vodovnik L, Malezic M, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 171-172, 1989.

**Effects of Electrical Currents on Wound Healing.** Vodovnik L, Karba R, Presern-Strukelj M, Erjavec T, Klesnik M, presented at the International Symposium in Honour of Luigi Galvani on *Electrobiology Today*, Bologna, Italy, 1989.

**Electrical Stimulation: A Generally Useful Perturbation in Medicine.** Vodovnik L, Stefanovska A, in *Proceedings of the Dresden Symposium on Electrostimulation*, 1989.

**Endogenous Potentials of Injured Skin.** Jercinovic A, Bobanovic F, Rebersek S, Karba R, Stefanovska A, Vodovnik L, *Electromagnetic Fields and Biomembranes*, Pleven, 1989.

**Experience with the Use of Electrical Stimulation in Healing the Wounds of Different Etiologies.** Karba R, Vodovnik L, Presern-Strukelj M, Erjavec T, Klesnik M, presented at *Bioelectric Repair and Growth Society (BRAGS)*, Cleveland, OH, 1989.

**Toward a Logic for the Effect of Electrical Stimulation on Wound Healing.** Stefanovska A, Vodovnik L, Kononenko I, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 173-174, 1989.

**Wound Healing Due to Electrical Stimulation: A Critical Review.** Vodovnik L, Stefanovska A, Turk R, Benko H, Malezic M, in *Proceedings of the Dresden Symposium on Electrostimulation*, 1989.



### [331] A Laboratory Test to Predict and Monitor Bone- and Skin-Related Complications in Spinal Cord Injury

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Sponsor: *Spinal Cord Research Foundation of Paralyzed Veterans of America; National Institute on Disability and Rehabilitation Research*

**Purpose**—Immediately after the trauma, spinal cord injury (SCI) patients have an increased rate of collagen synthesis, and an even greater increase in collagen degradation. The loss of collagen from bone, accompanied by loss of calcium, is implicated in the etiology of urinary tract stones, heterotopic ossification, and osteoporosis; similarly, the loss of skin collagen might lead to a propensity to develop skin ulcers. We have investigated these relationships by measuring the urinary concentration of two collagen metabolites: glucosyl-galactosyl hydroxylysine (glu-gal Hyl), which predominates in bone collagen. Normally, the ratio of urinary excretion of glu-gal Hyl to gal Hyl is 1.5. A higher ratio indicates preferential skin degradation. Conversely, a lower ratio indicates preferential bone loss.

**Methodology**—We measured the glycosides in aliquots from seven-day urine pools of male cervical and thoracic SCI patients, between 14 and 50 years of age, admitted to The Institute for Rehabilitation and Research (TIRR) for their initial rehabilitation, and on subsequent admissions or clinic visits for

approximately two years post-injury. The patients' medical records were examined to detect any instances of collagen-related complications which had occurred since the onset of SCI, in order to relate the appearance of these complications to the level of excretion of both hydroxylysine glycosides. Controls were co-workers with no known chronic disease.

**Results**—Patients with skin-related problems have significantly-increased urinary excretion of glu-gal Hyl, when compared to controls, or to patients with no complications. Patients with bone-related complications have significantly-increased urinary excretions of gal Hyl, when compared to patients without complications, or with controls. Additionally, the increased excretions begin before there are overt clinical signs of a developing decubitus ulcer or bone-related complications.

#### Publications Resulting from This Research

Collagen Metabolite Excretion as a Predictor of Bone- and Skin-Related Complications in Spinal Cord Injury. Rodriguez GP, Claus-Walker J, Kent MC, Garza HM, *Arch Phys Med Rehabil* 70:442-444, 1989.

### [332] Development of an Ischial Pressure Relief System for Quadriplegics Using Functional Electrical Stimulation

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Sponsor: *Scottish Home and Health Department*

**Purpose**—Our aim is to devise a method of pressure sore prevention in quadriplegic patients using functional electrical stimulation (FES). Despite many advances in seating design for spinal injury patients, pressure sores remain a major management problem accounting for between 25 and 50 percent of patient bed occupancy in our unit at any given time. We believe that patients with spinal cord injury gener-

ally do not perform regular pressure relieving push-ups either because they can not do so or have poor compliance. We have commenced a research program to develop a prototype FES system to provide regular ischial pressure reliefs in quadriplegic patients.

The application of FES to the quadriceps muscles in sitting patients causes knee joint exten-



sion. However, if knee joint extension is prevented, then bilateral quadriceps stimulation will cause elevation of the buttocks from the wheelchair, thus relieving sub-ischial pressures.

**Progress**—To date we have conducted trials on three patients who had been on an FES muscle conditioning program for gait studies. The extension of the knees was restricted by applying a broad padded strap across the mid-tibial area attached to the wheelchair. Bilateral simultaneous FES activation of quadriceps resulted in complete relief of sub-ischial pressures in all three patients as measured using an Oxford Pressure Monitor.

We have now commenced formal clinical testing to develop an FES system to produce regular ischial pressure relief for quadriplegic patients.

There are two main problems: 1) the development of suitable muscle stimulation parameters to offset any fatigue problems; and, 2) the inclusion of closed-loop control to turn off stimulation when pressure relief occurs. We have selected five quadriplegic patients who have commenced an FES muscle conditioning program and are currently undergoing baseline pressure monitoring.

**Future Plans**—When a suitable prototype system is developed, we plan to conduct a prospective clinical evaluation of its effectiveness in pressure sore prevention.

#### **Publications Resulting from This Research**

None reported.

### **[333] Electrical Muscle Stimulation for the Prevention of Pressure Sores. Part 1: EMS Effects on Seating Interface Pressure Variation, Tissue Shape Change, Muscle Blood Flow, and Skin Blood Flow**

S.P. Levine, PhD; R.L. Kett, MS; M.D. Gross; J.E. Juni; P.S. Cederna; B.A. Wilson; S.V. Brooks; D.B. Stutzman  
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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B351-RA)

**Purpose**—Pressure sores represent a severe and costly problem for many disabled individuals. This is particularly true for those who are wheelchair-dependent and have sensory loss. A research program has been implemented to determine whether electrical muscle stimulation (EMS) can be used to prevent the formation of pressure sores. The scope of this project is to investigate “immediate/dynamic effects of EMS” for pressure sore prevention. This investigation has included studies on pressure variation, tissue shape changes, muscle blood flow, and skin blood flow at the seating interface with EMS.

#### **Publications Resulting from This Research**

**Ischial Blood Flow in the Skin of Seated Individuals During Electrical Muscle Stimulation.** Kett RL, Levine SP, Wilson BA, Gross MD, in *Proceedings, ICAART 88*, Montreal, 324-325, 1988.

**Electrical Muscle Stimulation for Pressure Variation at the Seating Interface.** Levine SP, Kett RL, Bowers LD, Cederna PS, *J Rehabil Res Dev* 26(4):1-8, 1989.

**Blood Flow in the Gluteus Maximus of Seated Individuals During Electrical Muscle Stimulation.** Levine SP, Kett RL, Gross MD, Wilson BA, Cederna PS, Juni JE, *Arch Phys Med Rehabil* (in press).

**Electrical Muscle Stimulation for the Prevention of Pressure Sores: Tissue Shape Variation.** Levine SP, Kett RL, Cederna PS, Brooks SV, Stutzman DB, *Arch Phys Med Rehabil* (in press).

### [334] Electrical Muscle Stimulation for the Prevention of Pressure Sores. Part 2: Clinical Trials

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*Sponsor: VA Rehabilitation Research and Development Service (Project #B351-RA)*

**Purpose**—Continuing work on electrical muscle stimulation for pressure sore prevention focuses on small scale, short term clinical trials with newly spinal cord injured subjects. For this study a time series experimental design (A-B-A-B) is being utilized. Phase A involves sitting with no EMS for a predetermined time which will produce redness under the ischial tuberosities that persists for at least an hour following the sitting period. Phase B involves sitting for the same amount of time while EMS is provided via surface electrodes and a commercial stimulator. Parameters used to compare the EMS phase (A) versus the no-EMS phase (B) include skin temperature, size of erythematous area, and degree of erythema.

**Progress**—Preliminary clinical trials with three subjects showed muscle fatigue as a problem over the course of the trials, even with cycled stimulation. Stimulators were thus modified to provide intermit-

tent stimulation with long periods of rest in between cycled stimulation. Following this modification seven additional subjects were studied.

**Preliminary Results**—Preliminary results show changes in the measured parameters which tentatively indicate that EMS may help reduce erythema produced from sitting over extended periods with no pressure relief.

**Future Plans**—Complete statistical analysis of the results obtained from short term clinical trials will be performed over the coming year. These results will then be used to further evaluate the efficacy of EMS in preventing pressure sores under the ischial tuberosities.

**Publications Resulting from This Research**  
See Part 1.

## B. Fracture Healing

### [335] Testing of Design Parameters for a Prototype Piezoelectric Internal Fixation Plate

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*Sponsor: VA Rehabilitation Research and Development Service (Project #A019-3RA); Walter Scott and Lyons Foundation; New York State Department of Health*

**Purpose**—Our purpose is to develop a novel approach to electrical stimulation of bone healing that employs microampere currents generated during physiological loading of a piezoelectric material that is incorporated as part of an internal fixation plate. Alternatively, current at the optimum level can be

generated by external application of ultrasound to the skin over the plate. Thus, the "piezoplate" represents an implant that not only stabilizes bone, but also provides an internal source of electrical stimulation in response to physiological loading or low-level ultrasound.



**Progress**—To date, we have designed and tested several preliminary versions of the piezoplate. Because initial tests showed the piezoelectric ceramics placed in direct contact with bone were not effective, we developed a device in which the piezoelectric material is sealed within the plate and all charge developed is collected and delivered to bone via electrodes. In addition, a special miniature circuit has been developed to convert electrical charge generated by either mechanical loading (walking) or external ultrasonic activation into microampere DC current in the 5-20  $\mu$ a range (known to stimulate osteogenesis). Additional tests are being conducted on the standard rabbit tibia model to determine whether or not AC currents at ultrasonic frequencies may also stimulate bone formation. A canine model of non-union also has been developed specifically for testing of the piezoelectric plate on healing of a 2.5 cm gap osteotomy in the radius over a 3-month period.

**Results**—We have completed a final prototype design of the piezoplate. In this model, the piezoelectric elements are bonded to a rectangular inset in a six-hole titanium plate and waterproofed. Wires from the element extend to a separate encapsulated signal-conditioning package from which wires extend to the two platinum cathodes, which are placed within the osteotomy site. A platinum anode is bonded to one side of the circuit package. At present, a series of these units is being implanted bilaterally as fixation for 2.5 cm gap osteotomies in canine radii. As the healing pattern of these osteotomies at 3 months has been well documented

by us in prior control experiments, both limbs will receive active units so that both sides are exposed to electric currents generated from the piezoelectric element by weightbearing. On one side, however, we will augment the stimulation by ultrasonic activation of the element during the final 4 weeks of the 12-week test. Current is limited to 30  $\mu$ a divided between two cathodes. Currents generated in selected animals also are being monitored by external leads.

**Future Plans**—Our goal is to complete the above experiment in six to eight dogs with the facilities and funds currently available. While this will not constitute a definitive experiment in terms of final evaluation of the "piezoplate," the results should indicate whether or not this device warrants further development in the future by commercial or any other agencies.

#### Publications Resulting from This Research

**Design Considerations in Development of a Prototype Piezoelectric Internal Fixation Plate.** Cochran GVB, Johnson MW, Kadaba MP, Vosburgh F, Palmieri VR, *J Rehabil Res Dev* 24(2):39-50, 1987.

**Effects of Implanted Piezoelectric Materials on Osteogenesis.** Cochran GVB, Haboubi A, Palmieri VR, Kadaba MP, in *Proceedings of the 13th Annual Meeting of the Society for Biomaterials*, New York, NY, 150, 1987.

**Effects of Ultrasonically Generated Microampere Currents on Intramedullary Bone Formation in the Rabbit Tibia Model.** Cochran GVB, Palmieri VR, Kadaba MP, Mahaffey G, Schachter R, in *Proceedings of the 34th Annual Meeting, Orthopaedic Research Society*, Atlanta, GA, 1988.

**External Ultrasound Can Generate Microampere Direct Currents In Vivo from Implanted Piezoelectric Materials.** Cochran GVB, Kadaba MP, Palmieri VR, *J Orthop Res*, accepted for publication.

### [336] Electrophysiological Basis for the Prognosis of Fracture Healing

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**Sponsor:** VA Medical Center, Medical Research Service

**Purpose**—The purpose of this study is to determine if bioelectric characteristics of normal and delayed healing measured on the skin surface over fractures can be used for prognosis in fracture healing.

**Methodology**—Skin-surface voltages and currents are measured weekly during eight weeks following injury in three models, each involving osteotomy of the canine radius. A single-cut osteotomy of the



radius (producing a longitudinal gap  $<0.5$  mm), followed by transfixation to ulna with four Steinmann pins, is used as the normal healing model (NH). The same procedure, but without the transfixation, produces a delayed healing model (DH-1). Another delayed healing model (DH-2) is obtained by a 10 mm gap osteotomy followed by transfixation as defined above. The dogs are sacrificed at eight weeks, and the experimental and contralateral radii are excised and mechanically tested by three-point bending to determine rigidity. Statistical analysis of the correlations of rigidity with "bioelectric indices" derived from the skin-surface measurements, establishes difference in these indices that distinguish delayed healing (DH-1 or DH-2) from normal healing (NH) in our experimental models.

**Progress/Results**—We found that the voltage and current changed from positive to negative within one week in the NH model, whereas those changes occurred during 2 to 4 weeks in the DH-1 model. The voltage became positive again by the sixth week in NH, but remained negative through the eighth week in DH-1. In an experiment in progress, the models NH and DH-2 are being compared.

**Implications**—The proposed prognostic procedure can help to reduce the duration of disease and hospital care by enabling the physician to begin the most effective treatment available at an earlier time.

#### **Publications Resulting from This Research**

**Electrophysiologic Basis for Prognosis in Fracture Healing.**  
Chakkalakal DA, Wilson RF, Connolly JF, *Med Instrum* 22:312-322, 1988.

### **[337] Role of Osteogenic Growth Factor in Bone Healing**

**Richard T. Kao**

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**Sponsor:** *National Institute of Dental Research, National Institutes of Health*

**Purpose**—Current experimental approaches to bone development and healing have focused on the induction of bone formation by demineralized bone matrix (DBM). This induction is attributed to factors associated with DBM. These factors regulate various phases of osteogenesis by functioning in a cascade fashion. The mechanism of action for several of these factors has been elucidated, but little is known about the factor which regulates the proliferative phase of osteogenic cells. In preliminary studies, we have identified a DBM associated osteogenic cell mitogen which we have termed osteogenic growth factor (OsGF). The purpose of this project is to further purify and characterize OsGF.

The osteogenic proliferative phase represents a major portion of bone healing time. The shortening of this phase could significantly reduce the time necessary for bone healing. Preliminary studies indicate: 1) OsGF implanted into murine bone defects can reduce the proliferative phase from 12 to 6 days. This 50 percent reduction in the proliferative

phase results in a more rapid appearance of osteoids and osteoblasts; 2) OsGF addition to osteogenic cell cultures results in a four-fold increase in 3H-thymidine incorporation; 3) OsGF is a noncollagenous protein whose target cells appear to be restricted to cells derived from tissue that form bone under physiological and pathological conditions; and, 4) both platelet derived growth factor and fibronectin can serve as competence growth factors for OsGF. These studies indicate OsGF can shorten the proliferative phase and perhaps the overall bone healing time.

**Methodology**—The goal of the project is to purify OsGF from DBM and further characterize its biological and physical properties. To achieve this goal, cell cultures possessing osteogenic potential have been established and will serve as an appropriate target cell culture in which to monitor the purification of OsGF. The purified OsGF will be characterized in terms of its molecular weight, isoelectric point, and amino acid composition. Bio-



logical properties such as mitogenesis will be investigated to determine OsGF's effects on bone healing.

**Implications**—These studies will allow us to better understand the role of OsGF in the regulation of the proliferative phase of bone healing. This knowledge may contribute to future clinical use of factors such as OsGF in orthopedic, orthognathic, preprosthetic, and reconstructive surgery.

## C. Other

### [338] Enhancement of Wound Healing Using Synthetic Skin, Electrical Stimulation and Hyperbaric Oxygen Therapy

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Sponsor: VA Rehabilitation Research and Development Service (Project #A447-RA)

**Purpose**—This study evaluates facilitation of wound healing in an animal skin excisional model as well as in patients that have chronic skin ulcers. In addition, fibroblast growth on collagen matrices is evaluated in a cell culture system. The animal studies focus on optimization of healing of the dermis and epidermis in a well-controlled model. The human studies are directed toward translating animal studies into clinically useful treatment modalities.

**Methodology**—Fibroblasts are grown in culture on collagen beads to optimize cell division and replication rate. It is hypothesized that matrices optimized *in vitro* will enhance healing *in vivo*. Matrices containing fibroblast growth factor are implanted onto guinea pig excisional wounds and the strength is compared to control wounds. Collagenous materials composed of bovine hide collagen are formed into flakes by mechanically shearing collagen matrices: the flakes are packed into skin ulcers for clinical evaluation.

**Progress**—We have shown that fibroblasts replicate and synthesize proteins when grown in culture on a collagen sponge. In the presence of hyaluronic acid

### Publications Resulting from This Research

**Mitogenic Response of Cells in Culture to Demineralized Bone Matrix.** Huang DST, Kao RT, Shteyer A, Kaban L, *J Oral Maxillofac Surg* 46:460-463, 1988.

**A New System for the Histological and Biochemical Study of Bone Healing.** Kao RT, Convento JL, Kao JT, Wong AM, *Connect Tissue Res* (in press).

**Ascorbic Acid Modulates the Synthesis and Deposition of Glycosaminoglycans in Cultured Human Fibroblasts.** Kao JT, Huey G, Kao RT, Stern R, *J Cell Physiol* (in press).

and/or fibronectin, protein synthesis was maximized. In an animal skin excisional model, this collagen matrix promoted angiogenesis and remodeling of repair tissue and promoted healing. Results of clinical studies on patients with skin ulcers suggested that a 50 percent wound area reduction occurred during the first 6 weeks of treatment with collagen flakes. In comparison, no reduction of wound area was observed with control patients.

**Results**—In large scale cell culture, fibroblasts grow rapidly on collagen matrix beads. Optimization of cell growth occurs on beads that are cross-linked with glutaraldehyde compared to beads cross-linked with cyanamide or severe dehydration. Three days after seeding with  $5 \times 10^6$  cells/ml on each type of bead,  $8.7 \times 10^6$  cells/ml were observed on cyanamide and dehydration cross-linked collagen compared to  $2.88 \times 10^7$  on glutaraldehyde-treated collagen.

Collagen sponges containing fibroblasts or fibroblast growth factor were implanted on full thickness excisional wounds on guinea pigs; the tensile strength of the repair tissue was measured at intervals of up to 90 days post-implantation. At 15 days post-implantation, the tensile strength of



wounds treated with a collagen sponge containing fibroblasts or fibroblast growth factor was higher than that of wounds treated with a collagen sponge. These results suggest that the strength of animal excisional wounds can be increased by addition of fibroblasts or fibroblast growth factor.

Results of studies on human skin ulcers treated with collagen flakes containing 1 percent (W/W) hyaluronic acid indicate that the rate of wound closure is not significantly increased when compared to skin ulcers treated with collagen alone. In contrast to results of animal studies, initial results indicate that addition of hyaluronic acid to collagen does not facilitate healing of skin ulcers.

### [339] Morphologic and Ultrasonic Analysis of Normal and Ischemic Human Wounds

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Sponsor: VA Rehabilitation Research and Development Service (Project #A210-2RA)

**Purpose**—We have engaged in the investigation of deficiencies in the wound healing process in individuals with peripheral vascular disease (PVD) and diabetes mellitus (DM). We hope to identify abnormalities in the repair process which may suggest clinical interventions.

**Progress**—We have utilized standard incised wounds created with a Simplate II bleeding time device to produce uniform wounds on normal elderly subjects as well as patients with PVD or DM who are awaiting amputation. A variety of time points following wounding have been evaluated and differences in events of repair defined for several variables including PVD, DM, transcutaneous pressure of oxygen (TcPO<sub>2</sub>) and anatomic locations.

We have also studied the time table for appearance and disappearance of a number of proteins thought to be important to the repair process including thrombospondin, filaggrin, laminin, type IV collagen, SPARC and involucrins. Studies are underway with platelet-derived growth factor (PDGF), transforming growth factor (TGF $\beta$ ) and transforming growth factor (TGF $\alpha$ ). IL-1 and FGF antibodies are available for similar studies. Antibody to stain for the presence of nonenzymatic

**Future Plans**—During the final year of this project, additional clinical studies will be performed to evaluate the effect of collagen containing hyaluronic acid and/or fibronectin on the healing of chronic skin ulcers. Results of these studies will indicate whether a correlation can be drawn between excisional wound healing studies in animals and healing of chronic wounds in humans.

#### Publications Resulting from This Research

None reported.

glycosylation (NEG) of proteins has been successfully used to study human wound tissue. We are currently investigating the use of high frequency ultrasound as a method for noninvasive evaluation of the repair process. A scanning laser acoustic microscope (SLAM) is being used for the latter studies.

**Results**—We have now studied 24 patients with DM, 17 with PVD, and 25 normal elderly subjects. Morphological events of dermal repair are significantly advanced in the following observed states: 1) if TcPO<sub>2</sub> is greater than 21; 2) in the superficial wound compartment when compared to the deep wound; 3) in controls compared patients with PVD and DM; and, 4) in arm wounds compared to leg wounds. Epidermal events of repair were not different between controls, patients with PVD or DM. Wounds from diabetic patients stain much more intensely than normals for glucitolysine epitope (NEG).

**Future Plans/Implications**—Using biochemical methods we hope to be able to use our monoclonal antibody on the NEG to identify the specific proteins stained in the diabetic wound matrix and to



ascertain functional changes in these proteins which may be important in the pathogenesis of diabetic wound failure. We also plan to fully evaluate normal wounds and wounds from patients with PVD and DM for the presence of a variety of growth factor, as well as a time table for appearance and disappearance of those factors.

Our model is also well suited for the use of *in situ* hybridization techniques for assessment of repair parameters. We are hopeful that we can identify abnormalities in the repair process by comparing normal elderly subjects with individuals with PVD and DM. Experiments are also underway to assess the utility of high frequency ultrasound in assessing wound maturation. It may be possible to assess abnormalities in the material properties of wounds such as tensile strength and collagen content, as well as assessing images which may identify early evidence of wound failure.

#### Publications Resulting from This Research

**Reliability of Transcutaneous Oxygen Tension (TcPO<sub>2</sub>) Measurements in Elderly Normal Subjects.** Olerud JE, Pecoraro R, Burgess E, McKnight B, Wyss C, Reiber G, Matsen F, *Scan J Clin Lab Invest* 47:535-541, 1987.

- Thrombospondin in Early Human Wound Tissue.** Raugi GJ, Olerud JE, Gown AM, *J Invest Dermatol* 89:551-554, 1987.
- Ultrasonic Assessment of Skin and Wounds with the Scanning Laser Acoustic Microscope.** Olerud JE, O'Brien W Jr, Riederer-Henderson MA, Steiger D, Forster FK, Daly C, Ketterer DJ, Odland GF, *J Invest Dermatol* 88:615-623, 1987.
- An Assessment of Human Epidermal Repair in Elderly Normal Subjects Using Immunohistochemical Methods.** Olerud J, Gown A, Bickenbach J, Dale B, Odland GF, *J Invest Dermatol* 90:845-850, 1988.
- Biochemical and Acoustical Parameters of Normal Skin.** Riederer-Henderson MA, Olerud JE, O'Brien W Jr, Forster F, Steiger D, Ketterer D, Odland GF, *IEEE Trans Biomed Eng* 35:967-972, 1988.
- Measurement of Uncertainty Assessment of the Scanning Laser Acoustic Microscope and Application to Canine Skin and Wound.** Steiger D, O'Brien W Jr, Olerud JE, Riederer-Henderson MA, Odland GF, *IEEE Trans Ultrason Ferroelectr Freq Control* 35:741-748, 1988.
- A Method for Localizing the Early Products of Nonenzymatic Glycosylation in Fixed Tissue.** Kelly SB, Olerud JE, Witztum JL, Curtiss LK, Gown AM, Odland GF, *J Invest Dermatol* 93:327-331, 1989.
- The Systematic Study of Partial Thickness Wounds in Normal Elderly Adults and Patients with Peripheral Vascular Disease (PVD) and Diabetes Mellitus (DM).** Olerud J, Odland G, Burgess E, Wyss C, Fisher L, Matsen F, presented at the *Society of Investigative Dermatology*, 1989.
- Ultrasonic Assessment of Skin and Surgical Wounds Utilizing Backscatter Acoustic Techniques to Estimate Attenuation.** Forster FK, Olerud JE, Riederer-Henderson MA, Holmes AW, *Ultrason Med Biol* (in press).

### [340] Diabetic Foot Ulcers: Quantifying the Effects of Nonsurgical Treatments

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University of Washington, Seattle WA 98195

**Sponsor:** VA Rehabilitation Research and Development Service (Project #A318-2RA)

**Purpose**—We will characterize the natural history of healing of diabetic foot ulcers, and test the hypothesis that specific medical treatments will substantially improve the rate of healing. Specific objectives are: 1) to develop an objective method to quantitate the healing progress of cutaneous ulcers; 2) to identify biomedical characteristics of patients with diabetic foot ulcers which may predict the probabilities of ulcer healing, chronic wound failure, or other definitive medical outcomes such as limb amputation; and, 3) to compare the rates of ulcer healing among patients randomized to receive, in addition to standard treatment, intensive diabetes management for optimal control of diabetes, nutritional

supplementation with zinc and ascorbic acid, and standard medical-surgical treatment alone (control).

**Methodology**—Volunteer patients with diabetes and lower extremity ulcers are randomized prospectively according to a factorial analysis of variance design to receive various medical treatments identified above. They are treated and followed in the outpatient setting with quantitation of the rate of ulcer healing until total healing or other definitive medical outcome occurs. Patients are evaluated initially by: 1) recording an extensive medical history and examination of the lower extremity ulcer; 2) laboratory determinations including measurements of diabetic



control, plasma ascorbic acid and zinc levels; 3) vascular testing including measurements of transcutaneous oxygen tension, segmental Doppler blood pressures, and toe blood pressures; and, 4) neurologic testing to quantitate neuropathy. The rate of ulcer healing is quantitated over a defined four-week period of treatment, according to a method of tracing the ulcer contours sequentially and photography of lesions.

**Preliminary Results**—Diabetic ulcer healing has been studied in 50 subjects. Preliminary findings

suggest: 1) rate of healing of ulcers is linear in individual subjects who comply with medical therapy, including non-weightbearing; 2) local edema comprises capillary delivery of oxygen and is an important impediment to ulcer healing; and, 3) among diabetic foot ulcers, neuropathic non-ischemic ulcers are substantially more prevalent than ischemic ulcers.

#### **Publications Resulting from This Research**

None reported.

### **[341] Interleukin-1/Platelet Derived Growth Factor (PDGF) Effects on Oral Wound Fibroblast Glycosaminoglycans (GAG) Synthesis**

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**Sponsor:** *National Institute of Dental Research, National Institutes of Health*

**Purpose**—The specific aims of this project are to: 1) determine the capacity of two inflammatory mediator molecules, interleukin-1 (IL-1) and platelet derived growth factor (PDGF), to alter synthesis of glycosaminoglycans (GAGs) and proteoglycans (PGs) in culture by fibroblasts derived from normal oral mucosa, oral mucosal wound granulation tissue, and mature oral mucosal scar tissues; 2) determine whether fibroblasts derived from wounded and nonwounded tissues are equally responsive to the designated mediators in terms of cellular proliferation and GAG/PG synthesis; and, 3) determine if the GAGs and PGs, whose synthesis is induced by mediator molecules, subsequently exert direct influences on fibroblasts to perpetuate altered synthesis even after exposure to the mediator has ended.

Excessive scarring of oral and perioral tissues results from altered matrix metabolism and is a major clinical problem since normal functioning of mucosal structures depends upon their pliability, resilience, barrier function, and absence of strictures. Scarring impedes mastication, deglutition, nutrition, respiration, speech, and appearance.

**Methodology**—Fibroblastic lines will be derived from biopsies of normal (uninjured) mucosa as well as from reparative tissues harvested at intervals

from buccal mucosal wounds in New Zealand white rabbits. Type I cultures will be exposed to various concentrations of IL-1 or PDGF and then will be assayed for: 1) rate of cellular proliferation; 2) GAG composition and synthetic rate; and, 3) PG protein core composition and synthetic rate.

Selected cultures will be assayed for production of endogenous IL-1, endoglycosidases, and proteinases. After mediator-induced alterations in GAG/PG production are known, the GAG/PG isolated from Type I cultures will be introduced to a second set of identical cultures (Type II), which have not been exposed previously to mediator molecules. Type II cultures will then be assayed to establish whether the GAG/PG, whose synthesis is induced by mediators, can exert direct influences on fibroblasts to perpetuate altered matrix synthesis in the absence of mediator.

#### **Publications Resulting from This Research**

**Modulation of Dermal Fibroblast Growth and Glycosaminoglycan Synthesis by Interleukin-1.** Bronson RE, Bertolami CN, Siebert EP, *Collagen Relat Res* 7:323-332, 1987.

**Hyaluronidase Activity of Rabbit Skin Wound Granulation Tissue Fibroblasts.** Ruggiero SL, Bertolami CN, Bronson RE, Damiani PJ, *J Dent Res* 66:1283-1287, 1987.

**GAG Content of Healing Mucosal and Integumentary Wounds.** Ellis D, Damiani PJ, Day R, Ruggiero SL, Bertolami CN, *J Dent Res* 66:1328 (abstract), 1987.



### [342] Effects of Chlorhexidine on Human Fibroblasts In Vitro

**Jon C. Daniel**

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**Sponsor:** *National Institute of Dental Research, National Institutes of Health*

**Purpose**—Chlorhexidine is used clinically for the disinfection of operation sites, treatment of burns, and orally for the prevention of gingivitis and caries. A number of studies have suggested that *in vivo* application to healing wounds hampers the rate and strength of wound repair. Other studies have pointed to the toxicity of the drug *in vitro*. Our objective is to apply sublethal doses of the drug to human connective tissue cells *in vitro* and examine its effect on various parameters of wound healing.

**Methodology**—We will study the effects of the drug on fibroblast growth, on collagen and total protein

biosynthesis, and on collagen gel contraction. Collagen gel contraction will be used as a model of wound contraction, an important fibroblast-mediated event in wound healing. Our studies will utilize three different fibroblast types: human foreskin, human gingiva, and human periodontal ligament fibroblasts.

#### **Publications Resulting from This Research**

None reported.

### [343] Bone-Derived Cell Production of a Chemotactic Factor

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**Sponsor:** *National Institute of Dental Research, National Institutes of Health*

**Purpose**—The purpose of this research is to study a monocyte chemoattractant, CF-O, produced by a cell line derived from an osteogenic sarcoma. Monocytes arise from stem cells in the bone marrow, enter the circulation, and undergo final maturation to macrophages in peripheral tissue. Monocytes/macrophages are essential to wound healing, as demonstrated by delayed or incomplete wound healing in animals depleted to monocytes. The inflammatory, proliferative, and regenerative phases of wound healing require the participation of monocytes/macrophages, either through their phagocytic or secretory function.

Particularly important is the secretion of growth-promoting factors which are capable of stimulating cellular proliferation and angiogenesis. Monocytes/macrophages may also support the growth of solid tumors through the production of paracrine and angiogenesis factors. Because the majority of monocytes/macrophages which infiltrate a wounded site or a solid tumor are recruited from the peripheral vasculature, factors which regulate

monocyte chemotaxis are of considerable importance.

**Methodology**—The proposed studies include deducing the complete amino acid sequence of CF-O through characterization of the CF-O cDNA, studying transcriptional, translational, posttranslational, and secretory events in the production of CF-O, and describing its binding kinetics and stimulation of monocytes/macrophages. The constitutive synthesis of CF-O by a bone-derived cell line provides an opportunity to study a monocyte chemoattractant that may be important in osseous wound healing and in the growth of osseous tumors. This factor may provide insight into the potential control of monocyte chemotaxis by locally produced chemoattractants.

#### **Publications Resulting from This Research**

None reported.

# XI. Muscles, Ligaments, and Tendons

*For additional information on topics related to this category see the following Progress Reports: [12], [234], [235], [236], [238], [239], [249], [251], [253], [256], [272], [273], [281], [282], [283], [288], [309], [346], [408].*

## A. General Properties of Muscle

### [344] Surgery Simulation: Computer Models to Study Reconstructive Surgeries

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Sponsor: VA Rehabilitation Research and Development Service (Project #B554-RA)

**Purpose**—When the human body is impaired due to disease or trauma, function can sometimes be restored with surgical reconstruction. Such reconstructions, however, often compromise the capacity of the muscles to generate force and moment about joints. Lack of sufficient muscle strength or moment arm can leave the patient with weak or non-functional limbs. At present, surgeons have no quantitative tools to preoperatively evaluate the effect of a planned surgical procedure on muscle-tendon force and moment. As a result, the success of many reconstructive surgeries is marginal, and the innovation of new procedures is limited.

We believe that a more effective way to design reconstructive surgeries is to use computer models of the musculoskeletal system to understand the biomechanical consequences of surgical procedures. The purpose of this study is to develop computer models to study the effects of reconstructive surgeries on the complex behavior of the musculoskeletal system. We hypothesize that the body can be represented by computer models that capture the essential features of the musculoskeletal system and predict muscle-tendon forces and moments in three dimensions (3-D). We also hypothesize that use of such models will significantly improve the surgeon's ability to plan surgeries by providing information about the effects of a planned surgical intervention

on muscle-tendon moments. We expect that improved understanding of a surgical intervention will lead to more effective surgeries and therefore will improve the functional result.

**Methodology**—We will use computer models to simulate reconstructive surgeries of the lower extremities. We plan to study lower-extremity procedures first because of the importance of the lower extremity to patient mobility. We will investigate such issues as: 1) Which muscle is the best candidate to replace a lost muscle? 2) How much can a tendon be lengthened before muscle weakness occurs? 3) Is muscle weakness following a tendon transfer due to change in muscle-fiber length or moment arm? 4) Precisely where should the tendon of a transferred muscle be attached? and, 5) How should musculoskeletal geometry be modified to maintain muscle strength in a hip reconstruction? Computer graphics will be used to visualize the complex interactions among components of the musculoskeletal system, and as an important communication tool for interacting with surgeons. We will make recommendations for or against specific surgical procedures, and we will evaluate the usefulness of the models to surgeons.

To date, we have developed and validated a sagittal-plane model of the lower extremity. We



have successfully used a musculoskeletal model and a computer graphics display to simulate the Chiari pelvic osteotomy, a surgical procedure designed to treat pain and instability of the hip. The model has served well in our previous studies of planar muscle-tendon function. We now need to extend the

model to 3-D and to expand our surgical simulation capabilities to achieve our clinical objectives.

#### **Publications Resulting from This Research**

None reported.

### **[345] Noninvasive Electromyography**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #B496-RA)*

**Purpose**—Clinical diagnostic electromyography (EMG) currently uses intramuscular needle electrodes to record myoelectric signals for analysis. The use of noninvasive surface electrodes rather than needles would be less painful and more easily accepted by many patients, especially children. However, surface recordings are generally considered unsuitable for electrodiagnosis because of the attenuation and distortion imposed on the myoelectric signals by the subcutaneous tissues and skin. Recently, new electrodes, consisting of an array of small surface contacts whose outputs are combined via a spatial filter, have been developed to overcome some of this distortion. We are interested in developing methods to analyze surface-recorded signals, and in particular to decompose them into their constituent motor unit action potentials (MUAPs), whose configurational properties, firing rates, and conduction velocities can then be estimated.

**Progress/Methodology**—In some superficial muscles, such as abductor pollicis brevis, signals suitable for decomposition can be recorded differentially from a pair of small, closely-spaced electrodes. In other muscles, such as brachial biceps, better selectivity can be obtained by forming a linear combination of the signals from an array of electrodes (spatial filter). An array of electrodes can also provide multiple channels of data.

We have experimented with two types of electrodes: sharp pins that protrude from a plastic holder just enough (1 mm) to pierce the outer

keratin layer of the skin, and flat metallic pads 2 mm square used on dry skin without electrode paste. The pin electrodes have low impedance (200 kilohms) and good selectivity, thus resulting in less noise, quieter baselines, better common-mode rejection, and signals twice as large and with sharper rise times than those recorded by pads. The pad electrodes exhibit high impedance (>2 megohms) and high noise (10  $\mu$ V rms), but are completely noninvasive. Signals from both pads and pins can be amplified using a conventional electromyograph.

The surface EMG can be analyzed using a method called automatic decomposition electromyography (ADEMG) which we previously developed to analyze needle EMGs. Surface EMGs suffer from the loss of high-frequency detail which makes MUAPs less distinctive from one another and hence more difficult to identify. This can be compensated to some extent by the additional information in a second channel. Two channels also allow estimation of the MUAP conduction velocity based on the latency between MUAP arrival times at the two pickup points.

**Results**—Our preliminary studies point to the feasibility of using surface recordings for diagnostic EMG. We have been able to decompose EMGs from abductor pollicis brevis and brachial biceps, thus yielding MUAPs with shapes and firing rates not unlike those seen with needle electrodes and with conduction velocities similar to those reported in the literature.

**Future Plans**—Future work will involve refining the electrode design, tailoring the ADEMG algorithm for the special characteristics of the surface signal, and collecting data from normal subjects.

**Publications Resulting from This Research**

None reported.

**[346] Motor Control Deficiencies**

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*Sponsor: VA Rehabilitation Research and Development Service (Project #594-RA)*

**Purpose**—It is now clear that there are a number of neuromuscular system modifications that accompany the normal aging process and produce deleterious effects on the quality of motor performance. For example, older adults manifest problems in static and dynamic balance, increased postural and intentional tremor, decreased reaction time and speed of movement, and an overall decline in sensory and motor systems needed for activities of daily living. Fortunately, there are some compensatory mechanisms available to overcome these changes and maintain adequate motor function. The gain of the spinal stretch reflex can be altered to compensate for declines in central motor function. Appropriate training strategies may generate new ways to respond to postural perturbation tasks. Older adults may benefit from increased reliance on kinesthetic perceptual systems to compensate for the well-documented declines in static and dynamic visual acuity, figure-ground discrimination, and depth perception. The general aim of the proposed work is to document the modifications associated with disabilities caused by age-related ailments, such as stroke, and to develop an understanding of how they affect motor control. In addition, compensatory processes assisting in the maintenance of motor performance will be studied and their underlying physiological principles will be investigated so that these effects might be optimized to improve neuromuscular coordination in the aged.

**Methodology**—Specific scientific tasks include: 1) examining the behavior of motor unit firing rates in aged adults and comparing these quantitatively with such information for younger adults; 2) examining the amount and nature of motor unit synchronization during voluntary isometric contractions; 3) applying the concepts of common drive to motor studies of the aged during voluntary muscle activity; 4) examining the role of ipsilateral and contralateral cutaneous input in aged adults during reflexive and voluntary motor activity; 5) determination of the role of stiffness in motor control; and, 6) studying compensatory changes in spinal reflex behavior, changes in nerve conduction velocities as a result of normal aging and/or disease, and changes in motor unit size and behavior with advancing age.

**Implications**—These investigations will lead to the development of quantitative techniques to assess the degree of neuromuscular system changes resulting from injury or from the aging process. These techniques will be quantitatively effective as well as time- and cost-effective. The new information gained in these studies will be used also to derive new treatments based on scientific principles.

**Publications Resulting from This Research**

None reported.



### [347] Muscle Activation by Electrical Stimulation

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #B595-RA)*

**Purpose**—Age affects the neuromuscular system in a number of ways which have been described primarily qualitatively in the existing literature. A general loss of skeletal muscle mass, a decrease of individual muscle cross-section, a progressive denervation of muscle fibers, an increased percentage of type I fibers, a decreased diameter of type II fibers, a decrease of tendon elasticity, and a decrease in nerve conduction velocity have all been reported. Changes in muscle structure lead to lower strength, slower reaction time, lower endurance, abnormal posture, and joint problems. The issue of quantitative, nonsubjective, and noninvasive characterization of muscle properties and performance has never been systematically addressed. Electrical stimulation techniques may provide important tools to improve our understanding of age-related changes in muscle physiology far beyond the traditional application of electrodiagnosis. These techniques are particularly suitable for the elderly population because little or no cooperation is required and because of their suitability for quantitative measurements and selec-

tive muscle tests. Moreover, traditional electrodiagnostic techniques could be improved with the application of more modern signal processing methods. Artificial intelligence concepts might also provide previously unavailable tools to extract useful information from voluntary or electrically elicited ME signals detected with noninvasive electrodes.

**Methodology**—Specific tasks that will be carried out in this project include the development of non-subjective quantitative tests for muscle characterization; the development of appropriate age-specific electrical stimulation techniques; the evaluation of surface stimulation techniques, with specific interest in reducing muscle fatigue during stimulation; identification of electrical stimulation modalities to prevent muscle hypotrophy during immobilization; and the assessment of EMG biofeedback therapy.

#### **Publications Resulting from This Research**

None reported.

### [348] EMG Signals in Neighboring Muscles: Cross-Talk or Co-Activation?

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**Sponsor:** *VA Rehabilitation Research and Development Service*

**Purpose**—When monitoring myoelectric (ME) signal activity from two muscles in close proximity, one must be careful to assess whether the detected signals arise from activation of motor units within the muscle, or whether the signal is simply volume conducted from a neighboring muscle. This is especially important in studies which attempt to determine if the control scheme during high level physical activity includes the co-activation (or co-contraction) of two muscles that typically oppose each other as antagonists.

**Methodology**—Some of our recent studies have concentrated on determining the level of cross-talk found in contractions of the medial gastrocnemius and anterior tibialis muscles. These two muscles are commonly used as functional antagonists. Using a specialized electrode and the double differential recording technique, one can discriminate between a signal originating from the muscle fibers beneath the detecting electrode and a volume-conducted signal from another muscle. A bipolar surface electrode was positioned on the agonist muscle (either medical

gastrocnemius or anterior tibialis) and a four-bar electrode was placed on the antagonist.

Subjects were asked to perform isometric contractions that involved the medial gastrocnemius or the anterior tibialis. Absence of double differential ME activity detected at the four-bar electrode was considered an indication that the single differential

signal was due to cross-talk. Percentage of cross-talk was calculated by dividing the detected single differential activity of the resting muscle by that muscle's activity at its maximal voluntary contraction.

#### **Publications Resulting from This Research**

None reported.

### **[349] Advances in the Acquisition of Myoelectric Signals**

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**Sponsor:** *VA Rehabilitation Research and Development Service*

**Purpose**—The purpose of this project was the development of a new device to aid the experimenter in the collection of stable, high quality myoelectric (ME) signals, because the successful decomposition of a ME signal depends on the quality of the signal.

**Methodology**—A new system has been designed to interface our specialized multichannel needle electrode to our data acquisition system. This front-end system uses state-of-the-art connector and microchip technologies. Features include lightweight, flexible cables to allow for easy positioning of the electrode; modular, rack-mounted components to reduce equipment clutter in the experiment area and allow for off-site experimentation; and on-line impedance monitoring. Prototypes have proven successful in enabling the experimenter to collect clearer and more noise-free signals.

We currently use a Signal Quality Monitor (SQM) to continuously display the slope and amplitude of the ME signal while it is being detected with our needle electrode. Slope and amplitude are two important characteristics of the ME signal that help determine if the signal falls within the acceptable limits required for decomposition. Success with this device has led to the latest second-generation work, which includes expanding the device to monitor several channels simultaneously, expanding the range of audio feedback provided, and interfacing

the SQM with a graphics station to produce more informative feedback (for example, amplitude and firing density histograms). The new information from these modifications will produce preliminary decomposition data and allow immediate assessment of the quality and usefulness of the data.

Since a key factor in ME signal stability is the ability of the subject to produce smooth and stable muscle contraction, we have recently implemented a Force Feedback System. This system, which interfaces an Intel 8086-based microcomputer to our minicomputer systems, allows the experimenter to enter subject information and graphically presents a force trajectory for the subject to follow.

During the contraction, the subject attempts to trace this trajectory using the cursor as feedback. This assures both experimenter and subject of a stable muscle contraction and consequently higher quality data. Subject information and characteristics of the force trajectory are available for later analysis.

**Preliminary Results**—The improvements in signal quality produced by the new front-end system, SQM, and force feedback system have facilitated our ongoing investigations of motor unit behavior.

#### **Publications Resulting from This Research**

None reported.



### [350] Characterization of Back Muscles by Means of Electrical Stimulation

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*Sponsor: VA Rehabilitation Research and Development Service; Liberty Mutual Insurance Company*

**Purpose**—Promising results obtained from experiments on the tibialis anterior (TA) suggested the possibility of noninvasive muscle characterization by means of electrical stimulation. This led us to consider application of the technique to study other muscles whose properties are known to be different from those of the TA. Back muscles are more fatigue-resistant than other skeletal muscles. They are known to have a high percentage of type I fibers as well as small type II fibers.

**Methodology**—The longissimus dorsi (LD) and the ileocostalis lumborum (ILC) were chosen for their superficial location, association with back pain, and availability of histological data from the literature. Preliminary experiments show that these two muscles could be selectively activated with monopolar electrical stimulation, and M-waves could be elicited and detected with the double differential technique. The thick layer of connective tissue above these muscles reduces the amplitude of the surface myoelectric (ME) signals.

The correlation coefficient between the double differential signal is often poor. This leads to

unreliable estimates of conduction velocity (CV), probably due to the length of the innervation zone as compared to fiber length. Specific techniques were developed to limit the effect of these problems, although the experimental technique is still not completely satisfactory and leads to acceptable results in approximately two-thirds of the experiments.

Supramaximal stimulation (HLS) was used to elicit maximal M-waves while a lower amplitude (LLS) was used to elicit M-waves in the range of 25 to 35 percent of the maximal amplitude. Stimulation was applied on the main motor point of either the LD or the ILC with a monopolar technique using current pulses having a weight of 0.1 ms and rates of 16 Hz or 32 Hz. Preliminary analysis of the results indicate that the time course of spectral parameters and CV of back muscles display decrements smaller than those of the TA in agreement with the expectation of greater fatigue resistance of LD and ILC with respect to the TA.

#### **Publications Resulting from This Research**

None reported.

### [351] Myoelectric Signal Decomposition Technique

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*Sponsor: Liberty Mutual Insurance Company*

**Purpose**—This study is exploring a method to refine a technique of myoelectric signal decomposition. Myoelectric signal decomposition is a method for studying the behavior of individual motor units, as well as the behavior of populations of simultaneously active motor units. The method consists of three parts: signal detection, acquisition, and decomposition.

In recent years, refinement of the motor unit analysis procedure has concentrated on increasing

the speed and ease with which the analysis is performed. Improvements include development of alternate electrode configurations better suited to the detection of more complex signals; development of signal quality monitoring techniques to ensure stable signals are acquired for high-yield and successful decomposition; and, development of modifications to the decomposition algorithm to reduce operator interaction while maintaining decomposition accuracy. Additional work is underway to

develop real-time data acquisition and automatic signal decomposition capabilities.

**Progress**—A number of interesting motor control questions are being addressed which use the signal decomposition technique. For example, the interdependent nature of motor unit discharges or motor unit synchronization has been demonstrated by means of the decomposition procedure. An underlying mechanism is suggested.

The role of the central and peripheral nervous systems vis-a-vis "common drive" is being investigated, as well as the effects of aging and specific

movement disorders on the methods used to control muscle contractions. Changes in motor unit behavior due to the loss of skin sensory input are also being investigated. Motor unit firing behavior changes and other myoelectric changes occurring during fatigue and individual motor unit morphology, as it relates to motor unit recruitment and firing rate behavior, are being studied through the combination of the signal decomposition technique with the acquisition of ancillary signals.

#### **Publications Resulting from This Research**

None reported.

### **[352] Theoretical Issues of Common Drive Behavior**

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**Sponsor:** *Liberty Mutual Insurance Company*

**Purpose**—We are initiating several theoretical investigations which we hope will provide a deeper understanding of the common drive of human motor units. First, we will attempt to establish rigorous measures to assess the level of correlation between two biological signals. Second, we will develop a formal model of the total muscle force output and how it is related to motor unit firing behavior.

A basic tool in assessing the commonality of two signals is the cross-correlation function. A major part of this study is the development of a digital signal processing protocol that will make the cross-correlation function a reliable and accurate measure of common drive. We are currently investigating the effects of firing rate estimation, DC filtering of the computed motor unit firing rates and muscular force, the computation of the cross-correlation function, and the time interval over which the cross-correlation function is computed on the estimate of common drive behavior. With the aid of the force generation model to be developed, ranges will be established for each parameter of the cross-correlation function under varying circumstances, thus providing formal criteria for drawing

inferences about the strength of the correlation between the two signals. A model of muscle force will be developed using the sum of individual motor unit twitches driven by the corresponding motor unit firing rates. The model will incorporate the differences in twitch exhibited by motor units with different types of waveforms.

The delay observed between changes in motor unit firing rate and muscular force in actual experiments involving contractions with force reversals appears to be too long to be readily explained by the mechanical properties of individual muscle fibers. The model to be developed will find its major use in the attempt to explain this time delay. With the help of the model, contractions with various force levels will be simulated using physiologically known recruitment/derecruitment schemes and firing rate modulations. The effects of varying the level of common drive to the homonymous motor unit pool will be studied in an attempt to understand the effects of common drive on motor unit firing rates and muscle force production.

#### **Publications Resulting from This Research**

None reported.



### [353] Experimental Investigations of Common Drive Behavior in Human Motor Units

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Sponsor: *Liberty Mutual Insurance Company*

**Purpose**—Several years ago, we described an interesting feature of motor unit behavior in which concurrently active motor units increase and decrease their firing rates in a unified fashion. Even during a period of constant force, motor unit firing rates seem to fluctuate as if the controlling command to the motoneuron pool were from some common source. We call this behavior “common drive.” Our goal has been to gain a deeper understanding of this phenomenon. We have found that this common drive behavior is greater in proximal than distal muscles, is present in older adults, and may be dependent upon peripheral input.

**Progress/Preliminary Results**—During the past year, we have investigated the possibility that this common motor unit firing behavior exists among motor units of the muscle, the orbicularis oris, that controls movement of the lip. This muscle appar-

ently lacks muscle spindles, and thus is an appropriate system for studying the role of Ia peripheral input connections. A preliminary analysis of our results appears to demonstrate that the motor units in this muscle vary considerably in their firing rates. Nevertheless, there seems to be a mutual control scheme controlling the unit firing rates which, in some subjects, are quite strong.

In our studies of the role of suprasegmental input on common drive behavior, we have compared the results obtained from both right and left hands in right-handed subjects. Our data, obtained from the first dorsal interosseous (FDI) muscle, suggest that motor units in the dominant hand are more tightly coupled than those in the nondominant hand.

#### **Publications Resulting from This Research**

None reported.

### [354] On-line Processing of the Myoelectric Signal

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Sponsor: *Liberty Mutual Insurance Company*

**Purpose**—The myoelectric (ME) signal decomposition technique has proved useful in the study of the firing behavior of individual motor units and interactions of concurrently active motor units. Motor unit firing behavior is studied by analyzing ME signals obtained by selective indwelling electrodes during muscle contraction. The procedure consists of three parts: signal detection, acquisition, and decomposition.

**Progress**—Our recent work in signal detection and acquisition has produced advances in real-time data acquisition and on-line processing. Real-time data collection now significantly reduces the amount of time needed for experimental data processing, since

the time needed to redigitize the data following the experiment has been greatly reduced or completely eliminated. Moreover, signal quality and reliability have also been enhanced. To achieve these goals, the Motor Unit Laboratory has acquired a specialized Masscomp computer dedicated to high-speed data acquisition. Using this system and customized software routines developed by the staff, we can now immediately process and analyze data. As an example, we are now able to display data on a graphics monitor using high speed plotting routines following a muscle contraction. This display is used to determine optimum electrode location to improve signal quality. In addition, various parameters of the surface ME signal, such as median and mean

frequency, muscle fiber conduction velocity, and signal amplitude, can be quickly calculated and viewed for initial data analysis and determination of subsequent measurements.

Improvements in ME signal decomposition have also been achieved by implementing our decomposition algorithm on a dedicated workstation. The capabilities of this workstation have signifi-

cantly reduced the time required to classify the ME signal into constituent motor unit action potential trains. This greatly increases the efficiency of data analysis since experimental results are obtained in a shorter period of time.

#### **Publications Resulting from This Research**

None reported.

### **[355] Motor Unit Firing Behavior in Older Adults**

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**Sponsor:** *National Institute of Aging, National Institutes of Health; Liberty Mutual Insurance Company*

**Purpose**—This research entails exploration of neuromuscular function in adults during the aging process. This process is marked by a general deterioration of many physiological systems. While a number of researchers have reported descriptive changes in neuromuscular features of aged adults, the mechanisms underlying these changes have received inadequate attention.

**Preliminary Results/Implications**—We have embarked on a series of experiments to explore neuromuscular function in aged adults. Our initial studies of motor unit firing behavior have corroborated earlier findings indicating that there is an overall loss of motor units with age, and that some of the muscle fibers previously innervated by deteriorating motoneurons are reinnervated by neighboring motor units. A number of abnormal observa-

tions have also been noted. For example, in previous reports we have shown that an inverse relationship holds between the force at which a motor unit is recruited and derecruited and its firing rate at submaximal force levels. This relationship appears to be altered in aged subjects tested so far. Moreover, motor units which had been recruited at force levels above 40 percent of maximal voluntary contraction (MVC) were not derecruited until the force had declined to well below 20 percent MVC. These observations suggest that there may be some reorganization in the control strategies used to grade muscular force in aged adults. We have begun new experiments in this area to explore the role of antagonist muscle contraction in aged adults.

#### **Publications Resulting from This Research**

**Unusual Motor Unit Firing Behavior in Older Adults.** Kamen G, DeLuca CJ, *Brain Res* 482:136-140, 1989.

### **[356] Effects of Choline Blood Levels on Muscle Function**

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**Sponsor:** *National Institutes of Health*

**Purpose**—This study is part of a larger project regarding the role of choline as a dietary nutrient. Our research focuses solely on whether choline blood levels affect human muscle function. Choline is a quaternary amine which has two roles in normal

muscle function. It is a precursor to the biosynthesis of phosphatidylcholine, an essential component of muscle fiber membranes, and is needed to synthesize



acetylcholine (ACh), a neurotransmitter responsible for muscle activation.

**Methodology/Results**—Our subjects were fed normal or choline-deficient diets for three weeks with a control week before and after this period. Preliminary results show plasma concentrations of choline dropped 30 percent in the deficient group; no changes were observed in the control group. The subject's muscle function was tested by performing maximal voluntary and maximal stimulated contractions. We observed a significant increase (two to threefold) in the rate of decay of median frequency and conduction velocity during voluntary contractions in the choline-deficient group. This suggests an increased rate of fatigue in the deficient group as compared to the control group. Normalized M-wave area is a nonconduction velocity-related parameter obtained from the stimulated contraction that describes the summation of individual muscle fiber

action potentials. Measurements of normalized M-wave area showed a 16 percent decrease in the deficient group.

This result leads us to conclude that lower choline blood levels cause intermittent failure of neuromuscular junctions and lower depolarization levels of muscle fibers due to structural changes in membrane (which may occur as phosphatidylcholine is cannibalized to produce free choline). We hope that further analysis from single muscle fiber action potential data will quantify these two contributions. Another group of subjects with a choline supplemental diet was tested. No significant changes have been found in this group. The data to date are preliminary and await larger group sizes for detailed evaluation.

#### **Publications Resulting from This Research**

None reported.

### **[357] Skeletal Muscle Reaction to Immobilization**

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**Sponsor:** *Netherlands Organization for Research, Foundation for Biological Sciences*

**Purpose**—The purpose of this study was to predict the reaction of human skeletal muscle to immobilization regarding length, duration of immobilization period, and position of the limbs.

**Progress**—A muscle model, relating the architecture of the skeletal muscle to its functional capacity, was formulated and experimentally determined on rat calf muscle and various others. Application to human calf muscle, using morphological data of human cadavers was done. The model was also applied in a description of muscular growth. It is now being used in analyzing the effects of various periods of immobilization in different positions, leading to differing muscle lengths.

The work is part of a program on "form, function and coordination of skeletal muscles," in which we have tried to relate experimental analysis of animal muscular function to real life human movements in vertical jumping and running.

**Results**—Effects of 4- to 6-weeks immobilization of calf muscles in growing rats were studied. Slow twitch soleus muscle followed the general rule: sarcomeres were lost during immobilization in shortened position. Predominantly fast and pennated gastrocnemius muscle reacted with alterations in muscle fiber length and sarcomere number, as well as alterations in aponeurotic length. Depending on the period of immobilization, these reactions resulted in abnormal length-force relations normalized to optimum length and maximal force at that length after 4 weeks. After 6 weeks these relations were normal, suggesting that the tissues of the muscle were harmoniously working together again. In short-term immobilized muscles, the reactions of muscular and connective tissue components in pennated muscle were not functionally balanced.

**Future Plans**—The interrelationships of muscular and connective tissue in growing and functioning muscle will be studied in more detail.

#### **Publications Resulting from This Research**

None reported.

### **[358] Coordination of Muscles in Gait**

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**Sponsor:** *Netherlands Organization for Research, Foundation of Biophysics*

**Purpose**—The coordination of lower limb muscles has been studied when one is jumping up and down and when bicycling. Rules for the function of biarticular muscles were found. This project is to ascertain if these rules are applicable during normal walking and running.

**Progress**—Biarticular muscles play a unique role in transporting rotational energy from proximal to distal segments when a person jumps up and down. The muscles contribute to the mechanical goal of the movement—maximizing effective power at take-off. They compensate for the diminishing contribution to translation of the body's center of gravity by extension (rotation) of lower limb segments.

Timing of the activation of these muscles, as well as the fact that they co-contract with their antagonists, is important. In bicycling it appeared

essential that such co-contractions were instrumental in producing thrust, as well as direction of movement in the extending limb.

We have tried to validate these concepts in human walking and running by experimenting and modeling.

**Future Plans**—Jumping up and down, and the timing and geometrical properties of the system will be analyzed by modeling. We plan to use a model we developed that applies finite element analytic instruments to dynamical problems (SPACAR).

Force platform, movement, and electromyographic registration of long jumps, running, and walking will be analyzed.

#### **Publications Resulting from This Research**

None reported.

### **[359] Thigh Musculature and Knee Stability**

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**Sponsor:** *Orthopaedic Research and Education Foundation; National Science Foundation; Louisiana Board of Regents*

**Purpose**—It has long been suspected that contraction of the quadriceps contributes to anterior displacement of the tibia, relative to the femur, with undue stress applied to the anterior cruciate ligament (ACL). Furthermore, some indirect evidence exists to suspect that concurrent contraction of the hamstrings during extension may reduce the magnitude of the anterior displacement and somewhat relax the stress on the ACL.

The objectives of this study are to obtain direct evidence of the undue stress produced by quadriceps

contraction, and the stress relaxation produced by concurrent hamstrings activity.

**Methodology**—Fresh frozen cadaver knees were set in a specially-designed loading frame with the quadriceps and hamstrings tendons attached to cables estimating the muscles' line of action. The cables were guided over pulleys and could be loaded with weights as necessary. The knee was fixed at various flexion angles across the joint's range-of-motion.



A series of X-rays were taken for various loading conditions and flexion angles and digitized by a digitizer into a PC computer.

**Results**—Geometrical analysis showed that up to 6 mm anterior displacement of the tibia results from loading the quadriceps only in the near extension range (0 to 45 degrees flexion), while posterior displacement results in the more flexed range (45 to 120 degrees flexion). Concurrent loading of the hamstrings with as much as 10 percent of the quadriceps load can reduce the anterior displace-

ment of the tibia by over 50 percent in the 0 to 45 degrees flexion range.

**Implications**—These results have significant implications on the basic understanding of knee biomechanics, the development of new corrective regimens for ACL-deficient patients, and preventing joint damage in spinal cord injury patients subjected to knee extension as a result of functional electrical stimulation without antagonist co-activation.

#### **Publications Resulting from This Research**

None reported.

## **B. Muscle Fatigue**

### **[360] Muscle Fatigue and Respiratory Failure**

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The Pulmonary Center, VA Medical Center, Boston, MA 02130; NeuroMuscular Research Center, Boston University, Boston, MA 02215

**Sponsor:** VA Rehabilitation Research and Development Service

**Purpose**—Over the past two years, the Pulmonary Center and the NeuroMuscular Research Center have developed a liaison in an attempt to study the electrophysiological phenomena that takes place in respiratory muscles. Studies were performed on volunteer subjects and patients with emphysema and chronic bronchitis and geared toward evaluating the way respiratory muscles are coordinated and the genesis of respiratory failure. Further understanding of these phenomena may lead to strategies for improving muscle function in patients whose lung disease has left them little ventilatory reserve.

We have expanded our research capacity to include the use of animal models with lung disorders. We are evaluating the effects of lung diseases such as emphysema (induced by intratracheal administration of elastase) or pulmonary fibrosis (induced by the intratracheal administration of bleomycin) upon respiratory muscle function. We have already shown that a chronic elastic inspiratory load results in an increase in strength but not in the endurance of hamster diaphragms.

**Methodology**—Muscle strip preparations from the hamster diaphragm are being studied *in vitro*. A specialized array of surface myoelectric (ME) signal electrodes has been designed and tested for monitoring ME signal spectral parameters and conduction velocity from electrically-elicited contractions. The diaphragm muscle strip is also instrumented to record its contractile tension. A series of preliminary tests has been completed in hamster diaphragm strips removed from animals at 7 days and 30 days following bleomycin administration.

**Preliminary Results**—Significant differences in muscle twitch response and contractile fatigue rates were observed in the 30-day strips. These differences suggest that the diaphragm muscle adapts to the increased load associated with pulmonary fibrosis.

**Future Plans**—Verification tests are underway to demonstrate the ME signal assessment capabilities of this system. When successfully completed, we will

continue tests to study the ME measures of fatigue in the diaphragm associated with animal models of lung disorders.

#### Publications Resulting from This Research

None reported.

### [361] Muscle Fatigue and Back Pain

**S.H. Roy; M. Emley; C.J. DeLuca**

NeuroMuscular Research Center, Boston University, Boston, MA 02215

**Sponsor:** VA Rehabilitation Research and Development Service; Liberty Mutual Insurance Company

**Purpose**—As many as 75 million Americans now suffer from severe lower back pain, and each year seven million more people develop this problem. Despite the many millions of dollars spent on innumerable treatments for the back, the majority of patients have chronic, remitting symptoms. Improved methods for assessing back disorders could help to diminish the problem and the financial burden of this disabling condition.

**Progress**—We have developed and are implementing a technique to provide the clinician with an objective index with which to measure treatment outcome for lower-back musculature. This technique estimates the fatigue rate of contracting muscles by measuring the shift in the frequency spectrum of a surface-detected myoelectric (ME) signal. The dynamic interaction of synergistic back muscles during fatiguing contractions may be represented by “fatigue patterns” created by the frequency shifts occurring in different muscles. Differences in these patterns associated with lower-back disorders may represent functional disturbances in back muscles.

**Preliminary Results**—Data from numerous chronic lower-back pain patients and normal controls are being collected with the Back Analysis System and analyzed for several areas of investigation. First, we are continuing to document the repeatability of the ME signal parameters that comprise a fatigue pattern. Our first series of trials in the original restraining device resulted in high reliability measures. We are conducting similar reliability trials in

the portable restraining device for patients with low back pain and pain-free control subjects.

Second, we are investigating the recovery process of median frequency measurements of lower-back muscles following sustained fatiguing contractions. Recovery following fixed rest periods of 1, 5, and 15 minutes are compared for control subjects. Similar tests are underway for lower-back pain patients as well.

**Future Plans**—We are targeting specific subcategories of lower-back pain patients to be tested by our assessment technique. We have tested patients with at least a 6-month history of chronic back pain without radiographic evidence of spinal abnormalities. This group was tested according to the same protocols for previous tests on control subjects. We have also begun testing patients with structural spinal disorders pre- and post-operatively.

#### Publications Resulting from This Research

**EMG Assessment of Muscular Deficits Associated with Chronic Back Pain.** Roy SH, DeLuca CJ, Casavant D, Emley M, in *Proceedings of the 7th Congress of ISEK*, Enschede, The Netherlands, 451-454, 1988.

**EMG Spectral Analysis of Muscle Fatigue Associated with Chronic Lower Back Pain.** Roy SH, Casavant D, Gilmore L, DeLuca CJ, Emley M, in *Proceedings of the 10th Annual Conference of IEEE/Engineering and Medicine in Biology Society*, New Orleans, LA, 1886-1887, 1988.

**Objective Evaluation of Muscle Imbalance in the Lower Back.** DeLuca CJ, Roy SH, Gilmore L, in *Proceedings of the 10th Annual Conference of IEEE/Engineering and Medicine in Biology Society*, New Orleans, LA, 1716, 1988.

**Lumbar Muscle Fatigue and Chronic Back Pain.** Roy SH, DeLuca CJ, Casavant D, *Spine* 14(9):992-1001, 1989.



### [362] A Fatigue Protocol for Assessing Pressurized Glove Function

**S.H. Roy; C.J. DeLuca**

NeuroMuscular Research Center, Boston University, Boston, MA 02215

**Sponsor:** *Grumman Space Systems*

**Purpose**—A collaborative effort between our laboratory and Grumman Space Systems, an operating division of Grumman Corporation, was initiated during the past year. Our assistance was requested to develop a protocol and perform initial measurements to evaluate forearm and hand fatigue associated with the use of a pressurized glove. The glove is part of the pressurized space suit used by NASA astronauts during extravehicular activity (EVA). One reported difficulty associated with use of the gloves is the premature development of localized muscle fatigue in the forearm and hand. Our techniques and instrumentation for monitoring localized fatigue using the myoelectric (ME) signal appear well suited for this particular application because a noninvasive method requiring a relatively simple test procedure was indicated.

**Progress**—We have monitored surface ME signals from two hand muscles and two forearm muscles. The muscle groups selected are active during the

opening and closing of the hand. A simple gripping task at a specified duty cycle was studied to identify different levels of localized muscle fatigue for different glove configurations. Specialized low profile active electrodes were developed to detect the ME signal from within an instrumented, pressurized "glove box." All ME signals were processed by the IBM/MFM device. Preliminary measurements were conducted in our laboratory prior to actual on-site implementation.

**Results**—The results of the ME signal analysis indicate that fatigue effects are muscle specific and that the pattern of fatigue across muscles is different in the gloved hand condition than in the bare-handed condition. The procedures and analytical methods used in this study provided significant groundwork for future investigations.

#### **Publications Resulting from This Research**

None reported.

### [363] Comparison of Spectral Parameter Estimates of the Surface Myoelectric Signal

**G. Balestra; M. Knaflitz; R. Merletti**

Politecnico di Torino, Torino, Italy; NeuroMuscular Research Center, Boston University, Boston, MA 02215

**Sponsor:** *Politecnico di Torino; Liberty Mutual Insurance Company*

**Purpose**—Following the original work of Stulen and DeLuca (1980), mean and median frequency of the myoelectric signal power spectrum have been extensively used to monitor spectral shifts during sustained contractions. Other parameters, such as the mode or the ratio of power above a selected frequency to the power below it, were shown to be biased or to be unreliable; however, median frequency was shown to be preferable to mean frequency (MNF) because of lower sensitivity to noise. Recent papers reported that the estimate of the mean has a smaller standard deviation than the estimate of the median. This suggests that in low

noise conditions the mean might be the preferred parameter.

**Methodology**—The problem was investigated during the past year with a theoretical and an experimental approach. The theoretical analysis showed that the estimate of the median value of a population of independent and normally distributed random variables has a standard deviation 25.3 percent greater than that of the estimate of the mean. Analysis of computer simulated myoelectric signal and of stationary myoelectric signals detected on the tibialis anterior (TA) at a contraction level of 20 percent of



the maximal showed that the estimate of median frequency (MDF) has a standard deviation from 30 percent  $\pm$  13 percent to 60 percent  $\pm$  15 percent (depending upon the algorithm used for the spectral computation) greater than the estimate of the mean. This indicates that the mean should be preferred in stationary conditions.

Furthermore, it was observed that a three point moving average filtering applied to sequential MDF estimates would lead to statistically equal standard deviations for the two parameters with consequent loss of time resolution of the MDF estimate.

Time resolution is important in nonstationary conditions. To assess the behavior of the two parameters, voluntary contractions at 80 percent maximal voluntary contraction (MVC) level lasting 20 s were performed. The time course of MDF and MNF was interpolated with regression lines or exponential curves. The initial value (intercept) and the initial slope of the fitting curve were computed.

Results from 17 experiments showed that the normalized initial slope (initial slope/initial value) was  $3.77 \pm 2.27$  percent/s for median frequency and  $2.66 \pm 1.49$  percent/s for mean frequency. The difference was significant at the 0.05 level.

**Results**—As expected, these findings indicate that MDF changes more than MNF with fatigue because the skewness of the spectrum increases. During electrically elicited contractions, the myoelectric signal is almost deterministic and the two parameters are equivalent. Conclusively, MDF is less sensitive to noise and more sensitive to fatigue than MNF. However, its estimate is affected by a larger standard deviation that may be effectively reduced by a three point moving average filter.

#### **Publications Resulting from This Research**

None reported.

### **[364] Muscle Fatigue Monitor**

**L.D. Gilmore**

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**Sponsor:** *Liberty Mutual Insurance Company*

**Purpose**—The Muscle Fatigue Monitor (MFM) is an instrument that allows the objective measurement of muscle fatigue in subjects in both laboratory and field environment. The device has evolved through a series of stages, culminating in its present form. The MFM uses electrodes placed on the skin above the subject's muscle to calculate the median frequency of the myoelectric signals that occur during a sustained contraction. A portable device, the MFM has proven to be a powerful tool for studying the underlying process of muscle fatigue.

**Progress**—In an effort to make the MFM concept available to other researchers, we have developed a more generalized MFM instrument based on the popular IBM PC computer. Our goal was to create an integrated fatigue measurement system for both research and clinical environments. Such a system would allow researchers to investigate the fatigue process of more complex muscular activity.

The core of the new MFM system is the dual-channel median frequency processing card de-

veloped by our laboratory in 1986. When these cards are installed in an IBM PC series computer and coupled with appropriate software, they form a powerful and flexible data acquisition system. Unlike other signal processing techniques, this instrument can process up to 10 channels of fatigue-related information in real time and immediately present results to the experimenter.

**Implications**—This feature should prove useful for future clinical investigations. During the past year, the MFM system has been evaluated extensively in the Center's Muscle Fatigue Laboratory as the key component of the Back Analysis System. Using this system, researchers can investigate patterns of muscle activity over the entire region of the lower back, thereby obtaining a detailed picture of back muscle performance.

#### **Publications Resulting from This Research**

None reported.



### [365] Surface Electrode Design

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NeuroMuscular Research Center, Boston University, Boston, MA 02215

**Sponsor:** *Liberty Mutual Insurance Company*

**Purpose**—Clear and accurate detection of myoelectric (ME) activity from the surface of a muscle is a basic prerequisite for the comprehensive evaluation of muscle behavior. Most of our laboratory and clinical evaluations require some type of surface electrode to observe muscle signal properties such as amplitude, spectral shift, conduction velocity, and location of motor points. These parameters are useful in evaluating the status of an actively contracting muscle.

**Progress**—Over the past few years, we have developed several configurations of active surface electrodes that do not require the use of conductive paste or gels. Each electrode configuration is based around an electronic circuit containing a high impedance, low noise, differential preamplifier that is housed in a small, rugged, epoxy package.

We have found that these surface electrodes have the mechanical and electrical stability that is necessary for reliable and consistent low-noise ME signal recordings. We now use these standard electrodes in a vast majority of our laboratory experiments, such as those concerning muscle fa-

tigue. During the past year, 30 additional electrode units were produced in the Electronics Laboratory.

Based upon the experience gained using our laboratory's standard active electrode, we are developing new versions which will expand the electrode application to studies of dynamic contractions. These contractions occur in activities such as running or exercise and are a more realistic representation of typical muscle function. During dynamic contractions, rapid flexion and extension of a limb imposes continually changing stresses at the skin-electrode interface.

To address these issues, we are focusing on creating a secure electromechanical bond with the skin. Several low-mass, less obstructive electrode designs which preserve high signal fidelity are being fabricated. In conjunction with this project, we are formulating a series of standard testing procedures to evaluate and compare the electrical and mechanical performance of our surface electrode designs.

#### **Publications Resulting from This Research**

**None reported.**

### [366] Myoelectric Changes During Fatigue

**N. Paul; G. Kamen; C.J. DeLuca**

NeuroMuscular Research Center, Boston University, Boston, MA 02215

**Sponsor:** *Liberty Mutual Insurance Company*

**Purpose**—Many studies have shown that during a sustained contraction there is a shift in the myoelectric (ME) signal spectrum toward lower frequencies. This downward shift has been attributed to a decrease in the velocity of propagation of individual muscle fiber action potentials. Conduction velocity (CV) changes, however, cannot account completely for the observed spectral shifts. The goal of this study is to explain the decrease in median frequency of ME signals during fatigue when conduction velocity changes are minimal.

**Methodology**—ME signals will be detected during fatiguing isometric contractions using the selective surfaces of a specialized quadrifilar needle electrode, a monopolar signal from the needle cannula, and a bipolar recording from the surface of the muscle. The decrease in CV and the median frequency of the cannula and surface-detected signals will be calculated. The selective needle signals will be decomposed using ME signal processing and decomposition algorithms. Changes in motor unit firing patterns thus obtained will be analyzed during

sections of the data where the CV remains relatively constant but median frequency decreases. Specific parameters to be studied include mean firing rate, interpulse interval variability, and the level of motor unit synchronization activity. Changes in the num-

ber of active motor units and the recruitment thresholds will also be noted.

#### **Publications Resulting from This Research**

None reported.

### **[367] Muscle Fatigue Correlates for Concurrent Myoelectric and NMR Measurements**

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**S.H. Roy; M.J. Kushmerick; M. Maris; L.D. Gilmore; C.J. DeLuca**

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**Sponsor:** *Liberty Mutual Insurance Company; Brigham and Women's Hospital*

**Purpose**—The physiological correlates to the observable shift in the myoelectric (ME) signal frequency spectrum during fatigue are not completely understood. Although it is widely accepted that this spectral shift is related to a slowing of ME signal conduction velocity, the extent to which this phenomenon is related to a change in pH or energy sources within the muscle is not clear. The precise relationship between cellular biochemical events and the electrical manifestation of muscular fatigue has eluded investigators. One of the principal obstacles has been the invasive nature of available intramuscular substrates and metabolites. With recent technical advances in phosphorous nuclear magnetic resonance spectroscopy (NMR), intramuscular pH and other cellular biochemical events can be non-invasively assessed in resting or exercising muscle.

**Progress**—At the present time, we have nearly completed the modification and testing of ME and torque measuring devices to ensure compatibility with the high magnetic fields characteristic of NMR instrumentation. This work is being pursued through the collaborative efforts of this research

center and the Nuclear Magnetic Resonance Laboratory, under the direction of Dr. Martin Kushmerick, at the Brigham and Women's Hospital.

**Preliminary Results**—Preliminary measurements have been completed to identify optimal contractile force levels and test durations for establishing a protocol that will accommodate the signal requirements of both methodologies. This procedure will enable us to monitor the change in median frequency as a function of time during and following a sustained fatiguing contraction. The median frequency behavior will be compared to concurrent measures of pH and muscular high energy phosphate.

**Future Plans**—Future goals include the development of studies to establish causality between physiological measures and spectral parameters of the myoelectric signal.

#### **Publications Resulting from This Research**

None reported.



### [368] Postural Muscle Adaptability During Prolonged Spaceflight

**S.H. Roy; C.J. DeLuca; L.D. Gilmore; L.R. Young; R.V. Kenyon; D. Watt; M. Couris**  
 NeuroMuscular Research Center, Boston University, Boston, MA 02215; Man-Vehicle Laboratory, Massachusetts Institute of Technology, Cambridge, MA 02139; University of Illinois at Chicago, Department of Electrical Engineering and Computer Science, Chicago, IL 60680; McGill University, Aerospace Medical Research Unit, Montreal, Canada

**Sponsor:** *NeuroMuscular Research Center*

**Purpose**—The Center's experience implementing techniques to measure muscle fatigue noninvasively and objectively was called upon for the D-1 Spacelab mission. This preliminary study was undertaken as part of a more comprehensive investigation into the effects of prolonged spaceflight (near-zero gravity) on the vestibular and motor systems of the body. A protocol was formulated to test the muscle fatigue properties both preflight and immediately postflight for several postural muscles of the lower limb. The Muscle Fatigue Monitor and associated

signal processing software are being used to analyze the data. When completed, we hope to demonstrate the use of this technique for documenting the adaptability of postural muscles to near-zero gravity. The successful development of prophylactic exercises for future spaceflights will most likely be dependent on objective measures of this kind.

#### **Publications Resulting from This Research**

None reported.

### [369] Myoelectric Manifestations of Muscle Fatigue During Electrically-Elicited Contractions

**R. Merletti; R. Knaflitz; L.R. LoConte; C.J. DeLuca**  
 NeuroMuscular Research Center, Boston University, Boston, MA 02215; Politecnico di Torino, Torino, Italy

**Sponsor:** *Politecnico di Torino; Liberty Mutual Insurance Company*

**Purpose**—An artifact removal technique was developed to allow detection of surface myoelectric signals (SMES) during contractions that were elicited by surface electrical stimulation of a muscle motor point. A software package was developed for IBM XT/AT and for DEC VAX computers to obtain and plot absolute or normalized values of SMES amplitude parameters and muscle fiber conduction velocity (CV) versus time or versus one another and to provide linear or exponential fitting of the plots. The SMES amplitude parameters include average rectified value (ARV), root mean square (RMS), and spectral parameters (mean frequency [MNF] and median frequency [MDF]).

**Progress**—Twenty experiments were performed on the tibialis anterior (TA) of 10 normal human subjects to investigate the myoelectric manifestations of muscle fatigue during isometric/electrically elicited contractions that lasted 20 seconds. Voluntary isometric contractions were performed at constant

force levels (obtained with visual feedback) of 20 percent and 80 percent of the maximal voluntary contraction (MVC).

Supramaximal stimulation (high level stimulation [HLS]) was used to elicit maximal M-waves while a lower amplitude (low level stimulation [LLS]) was used to elicit M-waves in the range of 20 to 30 percent of the maximum amplitude. Stimulation was applied on the main motor point of the TA with a monopolar technique using current pulses that were 0.1 ms wide with frequency rates of 20, 25, 30, 35, and 40 Hz. Muscle fiber CV was obtained by cross-correlation between the double differential signals provided by the four-bar pasteless electrode. Spectral parameters MNF and MDF estimates were computed from the single differential signal.

**Results**—Amplitude parameters, spectral parameters, and CV obtained during stimulated contractions showed smaller fluctuations and better repeat-



ability than those obtained during voluntary contractions. This suggests that the variations of firing rate and of the motor unit pool, as well as the occasional synchronization of motor units, contribute to the instability observed during voluntary contractions. Intraexperiment repeatability was much higher than interexperiment repeatability. This indicated the critical role of the stimulation and detection electrode location in addition to the possibility of studying different portions of the muscle by changing location.

Different levels of fatigue could be induced by different levels and frequencies of stimulation. Relationships among myoelectric signal parameters became more evident during stimulation, showing good correlation between CV and spectra parameters and between CV and ARV.

Conclusively, the myoelectric manifestations of

muscle fatigue during electrical stimulation provide reliable data about muscle parameters and architecture. Further, the versatility of experimental paradigms and the quality of information may be much better than those obtained during voluntary contractions. This technique may also be used for identifying optimal location of stimulating electrodes and for optimizing FES systems using surface electrodes.

**Future Plans**—Additional work is underway to assess the full capabilities of this technique, the role of electrode location, and myoelectric manifestations of muscle fatigue extended to the region of force failure.

#### **Publications Resulting from This Research**

None reported.

### **[370] Power Spectrum Analysis: Patients versus Normal Controls**

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**Sponsor:** *Ontario Ministry of Health (The Physicians' Services Incorporated Foundation)*

**Purpose**—Since a number of reports have demonstrated spectral changes in electromyogram (EMG) signals during sustained isometric contractions, and in light of information that muscular abnormalities may play a significant role in back pain through their mechanical effects on other non-muscular structures, we have begun to record and analyze parameters of the EMG power spectrum of the paraspinal muscles, with regard to their ability to discriminate between normal controls and chronic back pain patients.

**Progress**—Investigations of the distribution of the data from answers to pain questionnaires revealed that our patients formed two distinctive subgroups with regard to pain behavior measures: patients who were physically active in spite of their chronic back problems, and patients who avoided any physical activity as much as possible. We have now investigated a sufficiently large number of normal controls and back patients to carry out multivariate statistical procedures on the EMG data collected with the median frequency monitor.

**Results**—In terms of the activity of the multifidus muscle, the physically passive patient group displayed elevated spectral changes towards lower frequencies, reduced variability in the density spectrum, and higher values of estimated initial median frequencies, when compared to normal controls and physically active pain patients. Measures of the activity of the iliocostalis lumborum did not contribute in any significant way to these group differences. Based on these findings, and on the available literature concerning the histology and physiology of paraspinal muscles, it is proposed that the observed characteristics of the physically passive patient group may be due to a reduced ratio of slow twitch to fast twitch muscle fibers in the multifidus.

**Future Plans**—We are continuing this investigation with emphasis on the differential assessment of back pain patients as derived from both the patients' symptom profile and their parameters of the EMG power spectrum.

#### **Publications Resulting from This Research**

None reported.



### [371] Power Spectrum and Histological Profile

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Sponsor: Ontario Ministry of Health (The Physicians' Services Incorporated Foundation)

**Purpose**—Our electromyogram (EMG) power spectrum analyses of paraspinal muscles in chronic back pain patients led us to conclude that some patients displayed a deficient endurance capacity in the multifidus muscle either because of a lower ratio of slow twitch/fast twitch muscle fibers, or a degeneration of Type I slow twitch muscle fibers.

**Progress**—We have now initiated a study to examine the possible relationship between EMG parameters of the power spectrum and the actual histochemical composition of the muscle. This study involves the collection of needle biopsy material from the

multifidus in a selected group of normal volunteers. Previous attempts to interpret the outcome of muscle biopsies, gathered during clinical surgery of the spinal disk, have been complicated by conflicting reports about the muscle fiber type composition in the patients studied. These variations, which may themselves have been due to adaptive changes, emphasize the need for the collection of further unbiased information about the histochemical structure of the paraspinal muscles.

#### **Publications Resulting from This Research**

None reported.

### [372] Effect of Endurance Training on the EMG Power Spectrum

**H.J. Biedermann; G.L. Shanks; W.J. Forrest**

Department of Rehabilitation Medicine, Queen's University, Kingston, Ontario K7L 3N6 Canada

Sponsor: Ontario Ministry of Health (The Physicians' Services Incorporated Foundation)

**Purpose**—Our investigations of the profile of paraspinal parameters in certain chronic back pain patients has indicated elevated changes towards lower frequencies, reduced variability in the density spectrum, and higher initial median frequency values. We have now begun to investigate the profile with regard to the effect of variations in physical activity in normal controls.

**Results**—Physically active adults (participating in regular, organized workouts) were compared with healthy, but sedentary, adults. Preliminary analyses of our data revealed a trend *opposite* to the one we had found in physically passive back pain patients. In addition, recovery scores, which previously had not discriminated between normals and patients, were now significantly elevated in the physically active group, indicating effects of increased intramuscular vascularization following initial isometric

contraction. With regard to the iliocostalis muscle, the physically active group also showed a decreased left/right side variability, probably due to the symmetrical and balancing effect of their training (weight lifting, rowing, calisthenics) on the muscle.

**Implications**—Since it has been suggested that the potential of human skeletal muscles adapt to changes in functional demand, the question arises as to whether the profile of muscular dysfunction observed in some chronic back pain patients can be viewed as being *quantitatively* different from profiles of sedentary and physically active normals, or if it indicates *qualitative* distinctiveness in these patients. The present study is part of a project to answer this question.

#### **Publications Resulting from This Research**

None reported.

### [373] Effect of Surface Cooling on the Fatigue Parameters of the Power Spectrum

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Sponsor: Ontario Ministry of Health (The Physicians' Services Incorporated Foundation)

**Purpose**—A few of the back pain patients seen in our laboratory reported an accentuation of lower back pain, associated with increased stiffness during cold, damp weather, and a rapid onset of back pain when they were exposed to cool air drafts (e.g., air conditioning, open windows). These symptoms seemed to be ameliorated by local heating or a hot shower, stretching exercises, or moderate activity. These weather- and temperature-related symptoms, which are part of the overall clinical picture of primary fibromyalgia, have as yet not received particular attention, although they appear to exercise genuine and consistent effects. In light of the muscular pathophysiology proposed as a cause of primary fibromyalgia, we have initiated a study to investigate the effect of surface cooling on muscle function, particularly evidence of metabolic muscle fatigue, as derived from parameters of the electromyogram (EMG) power spectrum.

**Methodology**—Prior to convective cooling of the L1-L5 region, paraspinal constant force contractions were carried out and EMG power spectrum parameters recorded with the median frequency (MF) monitor (baseline recording). Subsequent to the application of cold, the contraction trials were repeated three times, separated by a rest period which had previously been found to be sufficient to allow for complete metabolic recovery in the paraspinal muscles.

**Results**—In addition to confirming earlier observations of a close relationship between initial MF

values and temperature, our data revealed an accumulative process in the EMG fatigue parameter over the three constant force contractions. The rate of fatigue increased (following the application of cold) by about 170 percent in the iliocostalis and 65 percent in the multifidus muscle, the differences in increases in fatigue rates reflecting different degrees of intramuscular temperature reduction. These increased fatigue rates over contraction trials could be related either to an accumulation of acid by-products due to insufficient oxygen supply, or insufficient removal of metabolic by-products because of reduced muscular blood flow. Either mechanism could lead to an excessive formation and accumulation of lactic acid in muscle tissue which may eventually impede muscle contractions and make it increasingly difficult and painful to activate the muscles in question.

**Implications**—Given these findings, together with the persistent claim of sensitivity to cold with associated muscular pain in fibrositis patients, we have proposed that such patients may experience excessive vasoconstriction in some muscles as an adaptive response to changes in surface temperatures. We are presently exploring the means to investigate this hypothesis further.

#### **Publications Resulting from This Research**

None reported.



## C. Ligaments and Tendons

### [374] Treatment of Variable Partial Flexor Tendon Lacerations

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Sponsor: VA Rehabilitation Research and Development Service (Project #A505-RA)

**Purpose**—Penetrating trauma to the hand occasionally produces partial laceration of the digital flexor tendons. Despite several experimental studies investigating partial tendon injuries, the indications for repair of incomplete tendon lacerations remain controversial.

**Progress/Methodology**—Previous studies have focused on determining the tendon tensile strength, as this is the parameter most directly related to the probability of rupture. We attempted to create uniform partial lacerations of chicken profundus tendons involving 75 percent of the tendon cross-sectional area. Despite the use of a homogeneous animal population, postlaceration biomechanical testing of the tendons from 10 chickens revealed a high degree of variability between tendons from different animals as well as between corresponding digits of the right and left feet in the same chicken. This emphasized the inconsistency of the hand-cutting technique for creating a standard injury. A device was designed which uses standard scalpel blades to create a uniform laceration by leaving a constant area of tendon intact regardless of original tendon size or shape.

With the instrument we have called the "tenotome," tendons from a second group of 10 chickens were lacerated through 75 percent of their cross-sectional area. Biomechanical testing of the tendons cut with the tenotome showed significantly less variation when compared to the tendons cut by hand (F Test- $p < 0.01$ ). Having demonstrated that the tenotome can produce very consistent lacerations in tendons, we next used it to generate curves for the rupture strengths of partially lacerated chicken and human tendons. Flexor profundus tendons were harvested from the central toes of 35 chickens and from all the digits on 5 fresh cadaver hands. The tenotome was used to create partial lacerations of

the tendons leaving variable amounts of tendon intact. The saline-moistened tendons were then stressed to failure on an Instron materials testing system, and the rupture strength in newtons was recorded for each specimen.

Histologic sections of tendons were used to determine the cross-sectional areas of the intact tendon segments. Both chicken and human tendons demonstrated a near perfect straight-line relationship between intact tendon area and rupture strength in newtons (correlation coefficients 0.98 and 0.99). The slopes of the strength curves were significantly different, with the chicken tendons being relatively stronger than human tendons. Human tendons from different digits were found to vary in total cross-sectional area, but not in strength-per-unit area. Our data indicate that the tensile strength of partial flexor tendon injuries is directly proportional to the absolute cross-sectional area of tendon remaining intact, and only indirectly estimated by the relative percent area lacerated. Estimation of the area of the remaining intact tendon segment should prove a more useful clinical parameter than percentage of tendon lacerated.

**Future Plans**—Studies presently being completed are comparing the healing abilities of chicken tendon lacerations treated conservatively and surgically using histologic examination, as well as evaluation of both tendon tensile strength and gliding function.

#### Publications Resulting from This Research

**The Effect of Different Repair Techniques on the Strength of Partial Flexor Tendon Lacerations Over Time.** Hitchcock TF, Candel AG, Light TR, Sartori MJ, Patwardhan AG, in *Proceedings of the 35th Annual Meeting of the Orthopaedic Research Society*, 275, 1989.

**New Technique for Producing Uniform Partial Lacerations of Tendons.** Hitchcock TF, Candel AG, Light TR, Blevens AD, *J Orthop Res* 7:451-455, 1989.



### [375] Laser Biostimulation of Healing Tendons: A Pilot Study

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A964-PA)

**Purpose**—Prolonged immobilization of surgically repaired tendons produces several complications that retard the rehabilitation process. Because laser biostimulation quickens collagen synthesis in skin wounds, burns, and ulcers, we hypothesized that He-Ne laser therapy will quicken the healing process of tendons, and hence minimize the need for prolonged immobilization. Thus, the purpose of this study was to determine the ultrastructural, morphometric, and biomechanical effects of He-Ne laser biostimulation on healing tendons.

**Methodology**—Under adequate anesthesia, the right Achilles tendons of 71 rabbits were tenotomized, repaired, and immobilized. Thereafter, the animals were randomly assigned to five treatment groups and a control group. The tenotomized tendon of each treated animal was stimulated daily with He-Ne laser of 632.8 nm wavelength. Each group of treated tendons received the same energy density of laser therapy: thus five doses, namely 1, 2, 3, 4 and 5 mJ cm<sup>-2</sup> were utilized. On the 21st post-operative day, the tendons were excised and either processed for electron microscopy and subsequent morphometric analysis, or frozen at -70 degrees C in 0.09 percent NaCl until they were biomechanically tested on an Instron device.

**Results**—The modulating effects of laser therapy were clearly evident in the tendency of laser-treated tendons to shrink to sizes that were more akin to those of intact non-tenotomized normal tendons. Treated tendons were consistently smaller in size than controls ( $p < 0.001$ ); consequently, tendons treated at each dose level developed nearly twice the tensile stress of control tendons ( $p < 0.001$ ). Since laser-treated tendons did not gain significantly higher energy absorption capacity, ultimate tensile

strength and strain, our biomechanical findings suggest that He-Ne laser biostimulation modulates inflammation, the process of remodeling or both inflammation and the process of remodeling during tendon healing.

This suggestion is buttressed by our electron microscopic findings which showed that unlike control tendons, the fibroblasts and collagen fibrils of laser-treated tendons were mostly aligned in the longitudinal axis of the tendon. A striking electron microscopic observation was the presence of intracytoplasmic collagen fibril equivalents in the fibroblasts of laser-treated tendons. Although the biological significance of this observation remains unknown, the corresponding changes in the morphology of matrical fibrils suggest that biostimulation modulates fibrillogenesis as well. While the mean cross-sectional area (CSA) of laser-treated tendons ranged from 189.3 to 943.2 nm<sup>2</sup>, that of control tendons was 1646.7 nm<sup>2</sup>. Non-parametric ANOVA and subsequent post-hoc analysis revealed that the mean CSA of matrical fibrils were consistently smaller in laser-treated tendons than controls ( $P < 0.01$ ).

**Future Plans/Implications**—Our study has demonstrated for the first time that laser biostimulation modulates the ultrastructure, morphology, and biomechanics of healing rabbit Achilles tendons. Our findings suggest the need to: 1) study other wavelengths of laser; 2) identify treatment parameters that may optimize these effects; and, 3) based on available evidence, expound the clinical values of laser biostimulation. We intend to pursue these goals in the next phase of our studies.

#### **Publications Resulting from This Research**

None reported.



## [376] Ligament Insertions: Relations in the Moving Knee

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Sponsor: VA Rehabilitation Research and Development Service (Project #A363-RA)

**Purpose**—In knee ligament reconstruction, it is important that the reconstructed ligament not excessively tighten during knee flexion (which would overstress the graft), and also not loosen (which would fail to support the knee). Hence, its length should remain nearly constant during knee flexion. A reconstruction which has the constant-length property is termed *isometric*.

Isometric repairs are only possible for a small range of sites on the femur and the tibia. Prior to our research, there were no quantitative guidelines for locating these sites. The goal of our research is to establish quantitative guidelines for reliably obtaining an isometric reconstruction.

**Methodology**—We use advanced instrumentation to measure all 6-degrees-of-freedom of motion in cadaveric knees. Computer search techniques then locate all possible isometric repair sites. Three-dimensional (3-D) graphics, "isometry maps," then show where to place the graft.

**Results**—A comprehensive set of isometry maps has been published that describes techniques for reconstruction of the anterior cruciate, the posterior cruciate, and lateral extraarticular tenodesis of the iliotibial band. A similar manuscript is in preparation which describes isometric repair techniques for the medial and lateral collateral ligaments.

We have also published a description of isometric repair techniques in video journal form. The advantage of a video journal is that we can intercut our 3-D computer graphics with scenes taken through an arthroscope. Isometry maps are superimposed on the computer generated knee anatomy. This has effectively communicated our results to practicing orthopedic surgeons.

We are now extending our experimental methods to joints other than the knee. We have become

acutely aware that isometry is a necessary, but not sufficient, foundation for ligament repair. Even if the central fibers of a graft are perfectly isometric, our research indicates that the peripheral fibers are not. Also, large bending and twisting motions of grafts inevitably occur, and as a result, the anatomy and loading of fibers at bone tunnels becomes highly nonphysiological, which may impair the healing process.

**Future Plans**—We are now actively developing a theory of the mechanics of bending and twisting fibers.

### Publications Resulting from This Research

**Can the Peripheral Portion of an Anterior Cruciate Ligament Graft be Nearly Isometric?** Sidles JA, Larson RV, Garbini JL, Matsen FA, in *Proceedings of the 34th Annual Orthopaedic Research Society Meeting*, Atlanta, GA, 1988.

**Fiber-Fiber Interactions Within Finite Ligament Grafts.** Sidles JA, Garbini JL, Larson RV, Matsen FA, in *Proceedings of the 34th Annual Orthopaedic Research Society Meeting*, Atlanta, GA, 1988.

**Graft Placement and "Twist" in Isometric ACL Reconstruction.** Sidles JA, Larson RV, Garbini JL, Matsen FA, in *Proceedings of the 55th Annual American Academy of Orthopaedic Surgeons Meeting*, Atlanta, GA, 1988.

**Intraarticular Bone Anatomy as a Guide to the Isometric Repair of Anterior and Posterior Cruciate Ligaments.** Sidles JA, Larson RV, Downey DJ, Garbini JL, Matsen FA, in *Proceedings of the 34th Annual Orthopaedic Research Society Meeting*, Atlanta, GA, 1988.

**Ligament Length Relationships in the Moving Knee.** Sidles JA, Larson RV, Garbini JL, Matsen FA, *J Orthop Res* 6(4):593-610, 1988.

**Computer-Assisted Isometry Planning.** Sidles JA, Larson RV, *Video J Orthop* 3(6), 1989.

**Fiber Anatomy and Internal Stresses in Ligaments and Tendons: A General Geometric Theory.** Sidles JA, Clark JM, Garbini JL, in *Proceedings of the 35th Annual Meeting of the Orthopaedic Research Society*, Las Vegas, NV, 1989.

**A Simple Experimental Demonstration That Large Internal Pressures are Generated in Ligament Grafts.** Sidles JA, Clark JM, McQuade KJ, in *Proceedings of the 3rd Joint ASCE/ASME Conference, Biomechanics Symposium*, 101-103, 1989.



### [377] Structural and Functional Properties of Normal and Healing Ligaments: Part 1

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Sponsor: VA Rehabilitation Research and Development Service (Project #A188-3RA)

**Purpose**—Changes in the properties of ligaments and in the ligament insertions to bone with age have been described. The objectives of this study were to examine the gradual changes in medial collateral ligament (MCL) properties both before and long after epiphyseal closure and the influence of sex on these properties.

**Methodology**—Four age groups of male and female New Zealand white rabbits were studied: 3.5 months, 6 months, 12 to 15 months, and 36 months. Only females were examined at 48 months, as males of similar age could not be obtained. Following euthanasia, the hindlimbs were removed and roentgenographed to evaluate epiphyseal plate status. All structures of the knee except the MCL were removed prior to testing, leaving a femur-MCL-tibia complex (FMTC). The cross-sectional areas of the MCL were measured and then the specimens were loaded to failure. Load-deformation (l-d) curves were recorded, and failure modes noted. Using this data and strain-time curves, the structural and mechanical properties were evaluated.

**Results**—All FMTCs failed by tibial avulsion prior to 6 months of age, and in the mid-substance after 6 months. The structural properties of the FMTC changed with age in both males and females. There was an asynchronous rate of maturation for the

males and females. There were rapid and significant increases in the maximum load and stiffness of the FMTC prior to epiphyseal closure. These properties reached a plateau at 12 to 15 months and subsequently declined gradually. The shape of the stress-strain curve for the MCL substance did not change with age for the males or females. The tensile strength (stress at failure) and tangent modulus (slope of the stress-strain curve) increased with age until 12 to 15 months of age and then decreased slowly.

**Future Plans/Implications**—In this study, we noted that by 6 to 7 months the epiphyses were closed in males, but not in females. All of the 6-month-old female specimens failed by tibial avulsion, while the male specimens failed in the mid-substance at this age, thus yielding a higher ultimate load. In order to clarify the time course of maturation, particularly in females, additional age groups need to be examined, especially between 6 and 12 months. Further studies may also focus on the influence of exercise on these age and sex-related changes in the tensile properties of the MCL and the FMTC.

#### Publications Resulting from This Research

**The Effects of Age and Sex on the Biomechanical Properties of the Medial Collateral Ligament.** Ohland KJ, Weiss JA, Wang CW, Woo SL-Y, in *Transactions of the 1989 ASME Winter Annual Meeting*, San Francisco, 1989.

### [378] Structural and Functional Properties of Normal and Healing Ligaments: Part 2

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**Purpose**—We have developed a new injury model to study medial collateral ligament (MCL) healing in the rabbit. Although many experimental animal models have been used to examine MCL healing, few have included a concomitant injury to the ligament in sections to bone as observed clinically. Using a combined injury model, healing was evalu-

ated following conservative treatment or primary repair of the MCL.

**Methodology**—In both groups (repaired and non-repaired), the left MCL of each animal was surgically exposed, and a 2.5 mm diameter stainless steel rod was passed transversely beneath the ligament at



the joint line. A small notch was made on each side of the MCL at the level of the rod. The ligament was ruptured in tension by pulling on the rod, creating a "mop-end" midsubstance tear. In half of the animals, the torn ligament ends were surgically repaired, while those of the remaining animals were manually approximated. Six and 12 weeks post-operatively, half the animals in each group (repaired and non-repaired) were sacrificed, and healing of the MCL was evaluated by means of the varus-valgus (V-V) knee rotation and tensile properties of the femur-MCL-tibia complex (FMTC).

**Results**—No significant differences were seen in the V-V rotations or the tensile properties between the repaired and non-repaired groups at either 6 or 12 weeks, suggesting that in a model that combines MCL substance-insertion site injury, surgical repair of the MCL and conservative treatment yield similar results. At both 6 and 12 weeks, the V-V rotations of the repaired and non-repaired knee and structural properties of the repaired and non-repaired FMTCs (ultimate load, ultimate deformation, energy absorbed, and stiffness) were significantly different from those of the contralateral sham-operated knees ( $P < 0.01$  in all cases). There was a significant effect of healing time ( $p < 0.01$ ) on these properties. At 12 weeks post-operatively, all experimental specimens failed in the ligament substance, and the tensile strength and ultimate strain of both the repaired and non-repaired specimens were significantly less than that of the shams ( $p < 0.01$  in all cases).

**Future Plans/Implications**—Following 6 weeks of healing, all experimental specimens failed by tibial

avulsion, indicating that the model produces significant injuries to the tibial insertion site as well as the ligament substance. These biomechanical findings are supported by histological examination of the insertion sites. This suggests that this is a useful model of clinical injury and, therefore, is suitable for the long-term study of grade III MCL injury. We plan to evaluate healing 1 year post-operatively in both the repaired and non-repaired groups biomechanically and histologically.

### Publications Resulting from This Research

**New Experimental Procedures to Evaluate the Biomechanical Properties of Healing Canine Medial Collateral Ligament.** Woo SL-Y, Gomez MA, Inoue M, Akeson WH, *J Orthop Res* 5:425-432, 1987.

**The Effects of Increased Stress on Medial Collateral Ligaments: An Experimental and Analytical Approach.** Gomez MA, Ishizue KK, Lyon RM, Kwan MK, Wayne JS, Furniss MA, Woo SL-Y, in *Transactions of the 34th Annual Orthopaedic Research Society*, 13:194, 1988.

**Injury and Repair of the Musculoskeletal Soft Tissues.** S.L.-Y. Woo, J.A. Buckwalter (Eds.), Illinois: American Academy of Orthopaedic Surgeons, 1988.

**A New Method for Determining Cross-Sectional Shape and Area of Soft Tissues.** Lee TQ, Woo SL-Y, *J Biomech Eng* 110:110-114, 1988.

**Simultaneous Measurements of Strains in Two Surfaces of Tendons and Ligaments.** To SYC, Kwan MK, Woo SL-Y, *J Biomech* 21:511-514, 1988.

**Effect of Partial and Total Transection of the Anterior Cruciate Ligament on Medial Collateral Ligament Healing in the Canine Knee.** Ohland KJ, Marcin JP, Young EP, Lin HC, Horibe S, Woo SL-Y, in *Transactions of the 35th Annual Orthopaedic Research Society* 14:322, 1989.

**Medial Collateral Ligament Healing Subsequent to Different Treatment Regimens.** Gomez MA, Woo SL-Y, Inoue M, Amiel DA, Harwood FL, Kitabayashi L, *J Appl Physiol* 66(1):245-252, 1989.

### [379] Structural and Functional Properties of Normal and Healing Ligaments: Part 3

**Purpose**—Determination of mechanical (material) properties of ligaments by uniaxial tensile testing is dependent on both accurate measurements of cross-sectional area and tensile stress and strain. The recently developed laser micrometer system was utilized to measure the cross-sectional shape and area of the rabbit anterior cruciate ligament (ACL) and medial collateral ligament (MCL). Stress-strain relationships of each ligament were determined and

correlated with the arrangement of the collagen fibers.

**Methodology**—For 8 rabbits, one of the two hindlimbs were used to test a femur-ACL/ anteromedial (AM) portion-tibia complex (FATC/ AM) and the other to test a femur-MCL-tibia complex (FMTC). For uniform stress distribution in uniaxial tensile testing, only the AM portion of the

ACL was used. The cross-sectional shape and area of the mid-joint region of each ligament was determined using the laser micrometer method. The specimen was rotated at 3-degree increments through 180 degrees of rotation and an image reconstruction procedure was utilized to calculate the cross-sectional shape and area. Tensile testing was performed on the FATC/AM and FMTC by loading to failure. Tensile strain was determined using the video dimensional analyzer system. Cyclic stress relaxation and stress-strain curves were obtained for each ligament.

**Results**—Cross-sectional areas for the ACL, ACL/AM and MCL were:  $6.1 \pm 0.6$ ,  $3.6 \pm 0.5$ , and  $3.1 \pm 0.2$  sq mm, respectively. Normalized cyclic stress relaxation of the MCL was found to be greater than that of the ACL. Stress-strain curves for the ACL and MCL were different. The tangent modulus (slope of the stress-strain curve) was significantly lower for the ACL, than for the MCL ( $p < 0.01$ ). The tensile strength of the MCL was

nearly twice that of the ACL ( $p < 0.001$ ), while strain at failure was similar for the two ligaments ( $p > 0.1$ ). SEM examination of the cross-sectional arrangement of the collagen fibers demonstrated marked differences between the ligaments.

#### **Publications Resulting from This Research**

**A New Method for Determining Cross-Sectional Shape and Area of Soft Tissues.** Lee TQ, Woo SL-Y, *J Biomech Eng* 110:110-114, 1988.

**An Analytical Technique for Defining the Mechanical Properties of Ligament Tissues.** Gomez MA, Kwan MK, Woo SL-Y, in *Proceedings of the 1989 Joint Biomechanics Symposium at the 3rd Joint ASCE/ASME Mechanics Conference*, San Diego, CA, 1989.

**Comparison of the Mechanical Properties of the Medial Collateral and Anterior Cruciate Ligaments of the Rabbit Knee.** Newton PO, MacKenna DA, Lyon RM, Akeson WH, Woo SL-Y, in *Proceedings of the 1989 Joint Biomechanics Symposium at the 3rd Joint ASCE/ASME Mechanics Conference*, San Diego, CA, 1989.

**A Structural Model to Describe the Stress-Strain Behavior for Parallel-Fibered Collagenous Tissues.** Kwan MK, Woo SL-Y, in *Proceedings of the 1989 ASME Winter Annual Meeting*, San Francisco, CA, 1989.



## XII. Neurological/Vascular Disorders

*For additional information on topics related to this category see the following Progress Reports: [84], [107], [111], [158], [159], [237], [272], [361].*

### A. General

#### [380] Comparison of Treatment Programs for Multiple Sclerosis Rehabilitation

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Rocky Mountain Multiple Sclerosis Center, Denver, CO

**Sponsor:** *VA Rehabilitation Research and Development Service (Project #B395-SCI)*

**Purpose**—The goal of this project is to examine the effectiveness of interdisciplinary team care, coordinated by a nurse practitioner case manager, in comparison with standard neurological care for patients with multiple sclerosis. Our main hypothesis is that coordinated care by experienced practitioners will maximize patients' quality of life and may eliminate preventable complications of multiple sclerosis.

**Methodology**—Patients with definite or probable multiple sclerosis are evaluated at baseline, 6 and 12 months. Study measures include the Minimal Record of Disability for Multiple Sclerosis (MRD), the Sickness Impact Profile (SIP), patient satisfaction with health care, the Campbell index of life satisfaction, and enumeration of VA and non-VA medical expenditures. Patients at the Portland VA Medical Center (VAMC) will continue to receive comprehensive neurological care. Patients at the Denver VAMC will be treated in an interdisciplinary team clinic, managed by a nurse practitioner case manager. The team includes two neurologists, two physiatrists, a nutritionist, a clinical psychologist, a rehabilitation nurse, and the nurse practitioner. The team carries out a comprehensive evaluation of the patient's physical, psychological, and social status. Realistic care and rehabilitation goals are established

and the nurse practitioner ensures that the plans are effectively carried out.

**Preliminary Results**—A total of 145 patients have been enrolled at the Denver and Portland VAMC's. The average age is 47 years and 85 percent are male. The average score on the Expanded Disability Status Scale (EDSS) is 6.1 (SD 1.9, range 1.5 to 9.0). The patients at the Portland site are somewhat more impaired than the Denver patients when total scores on the Incapacity Status Scale (ISS) are examined; however, there is no significant difference in EDSS scores. The (SIP) was used as an alternative measure of health status to the MRD. There was no significant difference between the Denver and Portland patients on SIP scores. The patients had very high scores on the SIP with total scores of 28.4 (SD 12, range 2.3 to 75.8), Physical Subscale 32.4 (SD 15.1, range 0.98 to 64.7) and Psychosocial Subscale 25.6 (SD 16.2, range 0 to 96.9). Average SIP total scores for the general population are 2.5, while patients with low back pain score 18.7. The multiple sclerosis patients' scores are among the most elevated seen. The EDSS, ISS, and SIP appear to reflect different aspects of multiple sclerosis, since the correlations between the total scores and subscales are small. The initial patients are now completing the 12-month follow-up evaluations.

**Future Plans**—Our goal is to complete the 12-month follow-up by mid-1990. Preliminary results of 6-month evaluations were made available in the fall of 1989.

#### **Publications Resulting from This Research**

None reported.

### **[381] Magnetic Brain Stimulation for Evaluation of Cognitive Function in Epilepsy Surgery Patients**

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**Sponsor:** *Emory-Georgia Tech Biomedical Research Center*

**Purpose**—Our goal is to evaluate high-frequency magnetic stimulation of focal brain areas as a less invasive means of functional localization in patients being evaluated for epilepsy surgery. Slower stimulation has been used on thousands of patients and volunteers in several countries, and appears to be benign. At present, epilepsy surgery patients undergo intracarotid Amytal injections and/or direct electrical stimulation of the cerebral cortex.

**Methodology**—Two magnetic brain stimulators have been constructed. One is used for single stimulation, to refine measurements of electric fields, current distributions, and sites of stimulation. The other, a unique high-frequency stimulator with an alloy-core electromagnet, is being used in an attempt to alter local cortical function.

**Progress**—The first stimulator and a set of quadrupole-loop stimulus coils have been used to localize the actual site of magnetic motor stimulation in the human brain, and to estimate the electric field strength required for threshold stimulation. The high-frequency stimulator has been shown to have

clinically-significant effects on the lateralized language effects on the temporal and parietal cortex. Using the earlier results, we are attempting to optimize placement of the maximum electric field in the relevant areas of the brain.

**Future Plans/Implications**—The initial localization greatly improves theoretical understanding of magnetic brain stimulation in all contexts, and allows more precise estimates of the electromagnetic fields required for clinical effects. If noninvasive cognitive localization is successful, it will have major implications not only for seizure surgery evaluation but for the entire field of neuropsychology.

Further refinement of the cognitive tasks to be tested with high frequency stimulation is being investigated.

#### **Publications Resulting from This Research**

**An Alloy-Core Electromagnetic for Magnetic Brain Stimulation.**  
(Abstract) Davey KR, Chen J-S, Epstein CM, *Electroencephalogr Clin Neurophysiol* (in press).

**Localizing the Site of Magnetic Brain Stimulation in Man.**  
Epstein CM, Schwartzberg D, Davey KR, Sudderth D, *Neurology* (in press).



## [382] Maximal Exercise Performance of Individuals with Multiple Sclerosis: Influence of Disease-Related Muscular- and Temperature-Induced Dysfunction

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Sponsor: Levine-Rubenstein MS Research Fund

**Purpose**—The primary goal of this research is to evaluate the aerobic exercise capacity of individuals with multiple sclerosis (MS), and to determine factors that limit exercise capabilities in this patient population. Specific objectives include: 1) development of a recumbent cycle ergometer capable of operation in an air and water environment; 2) assessment of several fitness characteristics, such as pulmonary function, body composition, and leg muscle strength that might influence exercise capability; 3) evaluation of maximal aerobic exercise capacity; and, 4) comparison of the physiologic responses of this population with matched controls during prolonged recumbent cycling in air and water environments.

**Progress**—Eleven MS (Kurtzke 1-4) and nine able-bodied (AB) subjects have completed all phases of testing for pulmonary function, body composition, lower extremity isokinetic leg strength, maximal aerobic capacity, and submaximal aerobic endurance.

**Results**—No significant differences were found between groups with respect to pulmonary function to body composition. Results of the isokinetic strength testing indicated that the MS subjects had a consistently lower peak torque during concentric muscle action of the quadriceps (CONC-Q) and hamstrings (COCH-H) as well as during eccentric muscle action of the quadriceps (ECC-Q). However, the differences between groups were only significant during CONC-Q. Analysis of the tests of maximal aerobic capacity on land and in water indicated that AB subjects had a higher  $\dot{V}O_2$  peak under both environmental conditions. Eighty-nine percent of the AB subjects were able to cycle for 60 minutes during the submaximal aerobic endurance test at approximately

50 percent  $\dot{V}O_2$  peak; however, only 36 percent of the MS subjects were able to cycle for the same time. Environmental condition did not appear to influence exercise performance for either group. The MS group tested did not exhibit symptoms of the disease during exercise in air or water.

**Future Plans/Implications**—Results of this investigation illustrate that the protocols utilized in testing isokinetic strength, maximal aerobic capacity, and maximal aerobic endurance are effective techniques for exercise testing with this level of disability in the MS population. Having completed this investigation, future research will focus upon several issues: 1) examining the adequacy of using the present testing techniques with more disabled MS persons who exhibit disease-related symptoms during exercise in air; 2) exploring the possibility of using other modes of ergometry with this population; and, 3) examining the effect of the disease upon training response.

### Publications Resulting from This Research

**Metabolic Responses During Cycling in Water Versus Air.** Ponichtera JA, Davis GM, Glaser RM, Servedio FJ, Collins SR, *Med Sci Sports Exerc* 19(2):S83, 1987.

**Automated Autonomic Nervous System Function Analysis System.** Ezenwa BN, Figoni SF, Glaser RM, Ponichtera JA, Rodgers MM, Almeyda JW, in *Proceedings of the Annual Conference of IEEE/EMBS*, 10:1210-1211, 1988.

**Physiologic Responses of Men with Multiple Sclerosis During Aerobic Exercise.** Ponichtera JA, Glaser RM, Davis GM, Servedio FJ, Collins SR, *Med Sci Sports Exerc* 20(2):S35, 1988.

**A Recumbent Cycle Ergometer for Disabled Individuals.** Ponichtera JA, Glaser RM, in *Proceedings, ICAART 88*, Montreal, 158-159, 1988.

**Concentric and Eccentric Isokinetic Lower Extremity Strength of Multiple Sclerosis and Able-Bodied Individuals.** Ponichtera JA, Rodgers MM, Glaser RM, *Med Sci Sports Exerc* 21(2):S107, 1989.

**[383] Techniques for Making Connections  
with the Nervous and Musculoskeletal Systems**

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*Sponsor: National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—This project is intended to develop techniques and instrumentation for the acquisition and processing of neuroelectric signals from the central and peripheral nervous system in acute and chronic neurophysiological preparations. Because of this laboratory's continuing interest in sensorimotor neural activity during unrestrained movements, the project also includes development and fabrication of chronically implantable mechanical transducers,

catheters, and connectors. Also included is the development of computer programs of general utility for acquisition and the analysis of neuroelectric and mechanical records, as well as of neuro-anatomical material.

**Publications Resulting from This Research**

None reported.

**[384] Motor Control Systems in the Spinal Cord**

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*Sponsor: National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—This project is designed to provide information on the mechanisms operating within reflex systems in the adult cat spinal cord, which includes alpha motoneurons as the output link, as well as on the interconnections and interactions between reflex pathways and control systems descending to the spinal cord from supraspinal centers. Particular consideration is also given to interrelations between synaptic organization, intrinsic neuronal properties, dynamic behavior of the alpha motoneurons, and

the motor unit type, as defined by the physiological characteristics of the innervated muscle fibers. A variety of preparations are being used, including anesthetized or decerebrate animals as well as intact, freely moving cats. Electrophysiological and morphological data are being obtained.

**Publications Resulting from This Research**

None reported.

**[385] Neural Pathways Involved in Tactile Discrimination**

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*Sponsor: National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—The proposed research is part of a long-term project to increase our understanding of the tactile information-processing capabilities and limitations of the somatosensory system, especially those neural regions and systems responsible for processing tactile information derived from mechan-

ical stimulation of the glabrous surfaces of the hand. Specifically, it is designed to examine the functional properties and stimulus-response relationships of the single neurons of three spinal pathways which project, directly or indirectly, to the thalamic ventrobasal complex: the spinocervical tract, the



postsynaptic dorsal column system, and the spinothalamic tract.

Microelectrodes will be used to record extracellular activity of cell bodies or fibers in response to controlled mechanical stimulation of the glabrous skin of the raccoon's forepaw. Neurons will be identified as belonging to one of these three systems by antidromic electrical stimulation of the appropriate region of spinal cord or brain stem.

Specific parameters to be examined include modality and adaptive properties, absolute thresholds, and receptive field areas, as well as the effects of controlled mechanical stimulus velocity, displacement, and force on both dynamic and static discharge. Neurons will be sought which display properties suggesting excitatory or inhibitory convergences, and which display properties of feature detectors (e.g., preferential response to edges or laterally-moving stimuli).

The properties of neurons of the three spinal pathways will be compared with each other, as well

as with properties of both primary afferents and neurons of the cuneate nucleus and thalamic ventrobasal complex, previously studied in this laboratory.

**Implications**—These studies should contribute to our knowledge of the differential contribution of three major somatosensory pathways to the processing of tactile information acquired by a behaviorally salient tactile organ system, the forepaw or hand, especially in glabrous surfaces. This, in turn, should provide information relevant to the design of devices for the utilization of tactile information by individuals handicapped in other sensory modalities. Findings should also have neurological relevance to the differential diagnosis of spinal cord injury or disease.

#### **Publications Resulting from This Research.**

None reported.

### **[386] Damage-Induced Trigeminal Reorganization**

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*Sponsor: National Institute of Dental Research, National Institutes of Health*

**Purpose**—The proposed research will define the peripheral and central sequelae of trigeminal nerve damage and determine whether these consequences can be altered by treatment with neuronal growth promoters such as bovine brain gangliosides. The application is composed of six projects; each will examine one aspect of the reorganization that follows transection of the infraorbital nerve in either adult or neonatal rats.

Project 1 will employ electron microscopic multiple retrograde tracing, and electrophysiological methods to address issues of ganglion cell survival and reorganization of peripheral connectivity.

Project 2 will use transganglionic tracing and injection of individual, functionally characterized primary afferents with horseradish peroxidase (HRP) to determine the extent to which nerve damage or inactivation alters the primary afferent innervation of the trigeminal brainstem complex, and whether changes in the central arbors of

individual axons can be correlated with alterations in their peripheral connectivity.

Project 3 will concentrate on potential changes in the brainstem organization. In these experiments, novel morphometric techniques will be employed to delineate the effects of both deafferentation and removal of targets upon the survival of trigeminal brainstem neurons.

Project 4 will employ retrograde tracing, electrophysiological and HRP injection techniques to delineate the effects of nerve damage or inactivation upon the morphology, response properties, and projections of second order trigeminal neurons.

Project 5, like 4 and 3, will examine damage-induced changes in the organization of the trigeminal brainstem complex. In these experiments however, the emphasis will be upon monoaminergic pathways which are well-known to influence the responses of trigeminal neurons. Project 6 is concerned with the effects of treatment with bovine



brain gangliosides on neuronal survival, and the events that surround and may influence axonal regeneration by surviving neurons. A parallel series of experiments will also examine the effects of gangliosides on trigeminal ganglion cell survival and neuritogenesis *in vitro*.

#### Publications Resulting from This Research

**Anatomical Consequences of Neonatal Infraorbital (IO) Nerve Transection Upon Trigeminal Ganglion and Vibrissa Follicle Nerves in Adult Rat.** Klein BG, Renehan WE, Jacquin MF, Rhoades RW, *J Comp Neurol* 268:469-488, 1988.

**Effect of Neonatal Infraorbital Nerve Transection Upon Substance P- and Leucine Enkephalin-Like Immunoreactives in**

**Trigeminal Subnucleus Caudalis of the Rat.** Rhoades RW, Chiaia NL, Hess PR, Miller MW, *J Neurosci* 8:2234-2247, 1988.

**Neonatal Infraorbital Nerve Section in Rat Results in Peripheral Trigeminal Sprouting.** Chiaia NL, Allen Z, Carlson E, MacDonald G, Rhoades RW, *J Comp Neurol* 274:101-114, 1988.

**Structure-Function Relationships in Rat Brainstem Subnucleus Interpolaris. II. Low and High-Threshold Trigeminal Primary Afferents.** Jacquin MF, Stennett RA, Renehan WE, Rhoades RW, *J Comp Neurol* 267:107-130, 1988.

**Structure-Function Relationships in Rat Brainstem Subnucleus Interpolaris. III. Local Circuit Neurons.** Jacquin M, Golden J, Rhoades RW, *J Comp Neurol* (in press).

**Structure-Function Relationships in Rat Brainstem Subnucleus Interpolaris. IV. Projection Neurons.** Jacquin M, Barcia M, Rhoades RW, *J Comp Neurol* (in press).

### [387] Characterization of Back Muscles by Means of Electrical Stimulation

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**Sponsor:** VA Rehabilitation Research and Development Service; Liberty Mutual Insurance Company; Politecnico di Torino

**Purpose**—The promising results obtained from experiments on the tibialis anterior (TA) suggesting the possibility of noninvasive muscle characterization by means of electrical stimulation led us to consider the application of the technique to other muscles whose properties are known to be different from those of the TA. Back muscles are more fatigue resistant than other skeletal muscles and are known to have a high percentage of type I fibers as well as small type II fibers.

The longissimus dorsi (LD) and the ileocostalis lumborum (ILC) were chosen for their superficial location, association with back pain, and availability of histological data from the literature. Preliminary experiments showed that these two muscles could be selectively activated with monopolar electrical stimulation and M-waves could be elicited and detected with the double differential technique.

The thick layer of connective tissue above these muscles reduces the amplitude of the surface myoelectric signals. The correlation coefficient between the double differential signal is often poor, thus leading to unreliable estimates of conduction velocity (CV). This is probably due to the extent of the innervation zone as compared to the fiber

length. Specific improvements or techniques were adopted to limit the effect of these problems, although the experimental technique is still not fully satisfactory and leads to acceptable results in about two thirds of the experiments.

**Progress**—Supramaximal stimulation was used to elicit maximal M-waves while a lower amplitude was used to elicit M-waves in the range of 25 to 35 percent of the maximal amplitude. Stimulation was applied on the main motor point of either the LD or the ILC with a monopolar technique using current pulses having a width of 0.1 ms and rates of 16 Hz or 32 Hz.

**Results**—Preliminary analysis of the results show that the time course of spectral parameters and CV of the back muscles display decrements smaller than those of the TA, in agreement with the expectation of greater fatigue resistance of LD and ILC with respect to the TA.

#### Publications Resulting from This Research

None reported.



### [388] Capsaicin in the Treatment of Painful Peripheral Nerve Pathology

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**Sponsor:** *The Royal Ottawa Health Care Group, The Royal Ottawa Hospital*

**Purpose**—This is a two-phased project, the first being a pilot study to determine whether the use of capsaicin (a compound derived from red peppers) is beneficial in the reduction of pain caused by injury or irritation to peripheral nerve conditions.

**Methodology**—For the pilot phase, subjects will be enrolled in a single subject trial involving a baseline period of two weeks' pain recording before starting the capsaicin, a four-week trial using the drug, a two-week withdrawal period, then another four-week trial. This will be followed by a two-week observation period.

The patients will be selected and screened for peripheral nerve lesions causing pain. The pain must be of a chronic nature, having been present for at least six months, and not been effectively treated by other modalities or means. The pain will have to be within a fairly localized dermatomic area, with normal or good sensation levels, and completely intact skin surface.

Patients will be asked to complete a pain diary on a daily basis. Recordings will include the number

of hours of sleep, pain ratings at four times of day on a six-point scale, and a record of medications taken. The pain scale is based on the McGill-Melzack Present Pain Intensity Subscale.

**Progress/Results**—For the purpose of analysis, average daily scores will be computed for the pain scale, and visually charted to describe the pattern over time. This will reveal the usual level of pain without treatment, length of time before an effect is noticed after treatment begins, the extent of carryover when the withdrawal period begins, whether the pain increases to the baseline level, and whether significant changes are again observed during the next treatment period.

Patients are presently being assessed and selected for entry into the pilot study. Due to the limited number of subjects available, it is expected that the project will take approximately one year for completion.

#### **Publications Resulting from This Research**

None reported.

## B. Arthritis

### [389] Biochemical Analysis of Synovial Activation in Joint Dysfunction

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #A052-5RA)*

**Purpose**—This project is designed to study the biochemical mechanisms of synovial activation with particular emphasis on the regulation of the production of neutral metalloproteinases. Synovial activation is important pathophysiologically in arthritis

and probably contributes to the aseptic loosening of total joint replacement.

**Methodology**—Monolayer cultures of synoviocytes are used in this work. The HIG-82 line of synovial

fibroblasts is used for routine experiments with primary synoviocyte cultures employed to confirm key findings. Production of collagenase, gelatinase, and stromelysin is measured by assay of conditioned medium; a radioimmunoassay is used to measure prostaglandin E<sub>2</sub> (PGE<sub>2</sub>). The synovial production of interleukin-1 (IL-1) and related chondrocyte activating factors (CAF) is determined by bioassays. Abundances of collagenase and stromelysin mRNAs are measured by Northern blot analysis using cDNA probes.

**Progress/Results**—Various activators, such as wear particles, transition metals, and IL-1 induce the synovial synthesis of the three neutral metalloproteinases and PGE<sub>2</sub>. The cytokines, including IL-1 produced by activated synoviocytes can, in turn activate chondrocytes and resting synoviocytes. The latter finding implies that synoviocytes can activate themselves in an autocrine fashion.

Induction of collagenase and stromelysin is preceded by the appearance of their mRNAs, sug-

gesting a pretranslational level of regulation. Preliminary experiments have failed to implicate Ca<sup>2+</sup> or cyclic nucleotides as second messengers for enzyme induction. However, marked changes occur in the patterns of cellular protein phosphorylation compatible with the activation of a protein kinase.

### Publications Resulting from This Research

**The Biochemical and Histological Effects of Artificial Ligament Wear Particles: In Vitro and In Vivo Studies.** Olson EJ, Kang JD, Fu FH, Georgescu HI, Mason GC, Evans CH, *Am J Sports Med* 16:558-570, 1988.

**Characterization of Chondrocyte Activation in Response to Cytokines Synthesized by a Synovial Cell Line.** Sung K, Mendelow D, Georgescu HI, Evans CH, *Biochim Biophys Acta* 971:148-156, 1988.

**HIG-82: An Established Cell Line from Rabbit Periaricular Soft Tissue which Retains the "Activatable" Phenotype.** Georgescu HI, Mendelow D, Evans CH, *In Vitro* 24:1015-1022, 1988.

**Induction of Collagenase mRNA in Lapine Articular Chondrocytes by Synovial Factors.** Lin CW, Phillips SL, Brinckerhoff CE, Georgescu HI, Bandara G, Evans CH, *Arch Biochem Biophys* 261:351-354, 1988.

## C. Low Back Pain

### [390] Evaluation of Psychophysiological Ways to Assess Chronic Low Back Pain

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #A367-RA)

**Purpose**—The purpose of this study is to evaluate the effectiveness of psychophysiological ways to assess chronic low back pain.

**Methodology**—Subjects with low back pain are given a complete physical examination and other objective medical tests. They are interviewed by a psychologist, and given both a standard and a specially-modified Minnesota Multiple Personality Inventory (MMPI), and then participate in four weekly muscle tension and heat pattern recordings while experiencing various intensities of low back pain.

**Results**—Initial results indicate that subjects with low back pain do not change many of their MMPI responses depending on whether or not they are in pain when answering the questions. To date, we have not found clear relationships between low back or leg thermograms, and either intensity or diagnosis of low back pain. Paraspinal muscle tension correlates well with pain intensity, but results differ somewhat depending on the diagnosis. However, people producing asymmetrical thermograms (different at greater than one degree C) tend to produce normal surface electromyograms (EMGs) and vice-versa.



**Future Plans**—The Army has funded a study in which we will use inconspicuous, ambulatory EMG and movement recorders to make continuous, week-long records of subjects with and without low back pain while subjects function in their normal environments. This will permit us to evaluate predictive relationships between changes in muscle tension and changes in low back pain.

### Publications Resulting from This Research

**Electromyographic Recordings of Five Types of Low Back Pain Subjects and Non-Pain Controls in Different Positions.** Arena J, Sherman R, Bruno G, Young T, *Pain* 37:57-65, 1989.

**Reliability of Multiple Surface Electromyographic Recordings of the Paraspinal Muscles Among Subjects With and Without Low Back Pain.** Arena J, Sherman R, Bruno G, *Int J Psychophysiol* (in press).

## [391] Back Pain

**Carlo J. DeLuca, PhD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #B593-RA)

**Purpose**—Disability, functional impairment, and pain are the symptoms of lower back disorders that affect approximately 80 percent of the adult population as a result of age-related changes in the spine. The overall impact to society in terms of decreased quality of life, lost work productivity, and medical expense can be measured in billions of dollars per year in this country alone. Age-related changes in the spine result in a decrease in the amount of motion present and alter the overall alignment of the spine. Neurological abnormalities secondary to degenerative changes in the spine also increase with age in both men and women.

Other important components of the spine complex include muscles, tendons, and ligaments. These structures are all important in the transmission of forces across the spine and intervertebral unit. These tissues are also subject to changes with aging. It is known, for example, that the force-generating capacity of skeletal muscles is reduced with aging, and that muscle endurance capacity in the aged may be even more seriously compromised.

Further work is necessary to delineate the specific role of these structures to alterations of the spine and to the high incidence of lower back disability among the aged population. We propose to study the extent to which age-related changes of the musculoskeletal system are responsible for lower back pain disability.

**Methodology**—Elderly individuals with a positive history of low back pain will be compared to normal controls on the basis of electromyographic (EMG)

evidence of muscle dysfunction. A large body of research has advanced the applicability of non-invasive EMG techniques for quantifying muscle fatigue in answer to clinical questions. We propose to implement these techniques to identify and measure the muscular component of lower back pain. We have had much success in demonstrating its usefulness for younger individuals with chronic back pain and wish to extend these studies to the aged population as well.

We will develop a biomechanical model of the spine and an anatomical database of spinal muscle cross-sections from CAT scans and/or magnetic resonance imaging (MRI) scans. We propose to combine this work with our muscle fatigue work and develop a Back Analysis System that will provide a means for objectively evaluating the presence or absence of back pain by measuring the rate at which the muscles of the back fatigue with respect to each other. This will be a stand-alone, portable system which can be located in clinical settings. A complete system should be available within 4 years.

**Future Plans/Implications**—We propose during the next 5 years to begin work on a Computer-Aided Physical Exercise Program. This is a long-term project (10 years) based on the union of our Back Analysis System with a computerized biomechanical model of the lower back. The model would be individualized by obtaining MRI-based measurements of back muscle and skeletal geometry. The system would input the muscle fatigue information into the model and a prescription of the optimal



exercise program (i.e., therapy) would be determined and presented to the therapist.

#### Publications Resulting from This Research

None reported.

### [392] Low Back Pain Studies

**Malcolm H. Pope, PhD; Martin H. Krag, MD; William Cats-Baril, PhD; Rowland Hazard, MD; Mary Moffroid, PhD; Steven Reinecke, MSME; David Wilder, PhD; Jerry Weisman, MSME; Antonia Clark, MS; Janice Clements, BS**

Vermont Rehabilitation Engineering Center, Burlington, VT 05401

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The Vermont Rehabilitation Engineering Center (REC), now in its second 5-year funding cycle, is committed to improving the prevention, treatment, and rehabilitation of low back pain through an integrated program of basic and applied research and information services. Specific objectives of the multidisciplinary center include: identification of risk factors for low back injury, pain, and disability; development of new measurement methods for diagnosis and research; evaluation of treatment programs and modalities; worksite assessment and modification; service delivery; information dissemination and training.

Affiliates of the Vermont REC include the New England Back Center, which operates a comprehensive rehabilitation program for chronic low back patients; The Vermont Spine Center; and Rehabilitation Technology Services, providing service delivery to individuals with low back and other disabilities.

**Progress**—Several research projects are currently under way in the following areas:

**1) Prediction of Disability and Assessment of Rehabilitation Strategies.** *William Cats-Baril, PhD.* The REC continues its pioneering work on prediction of low back disability and construction of a comprehensive and accessible database on individuals with low back pain. Treatment studies have been initiated to determine treatment outcomes among different subsets of patients. Additionally, the project team aims to determine cost-benefit ratios for various rehabilitation techniques.

**2) Intervertebral Motion and Muscle Use Detection.** *Martin Krag, MD.* This project was designed to develop a methodology for characterizing intervertebral motion and muscle use patterns in the lumbar spine. The design and fabrication of neces-

sary equipment and software have been completed and *in vivo* testing has begun.

**3) Lifting Capacity.** *Rowland Hazard, MD.* Dr. Hazard has developed a prototype lifting simulator that provides an index of subject effort and promises to be a practical, reliable, and inexpensive means of determining lifting capacity for a wide range of occupational health practitioners.

**4) Exercise and Physical Conditioning.** *Mary Moffroid, PhD.* This project comprises several discrete studies designed to study the endurance, eccentric capability, and time to response (to postural shifts) of the muscles surrounding the lumbar spine. Long-range goals include designing effective measurement tools and treatment programs.

**5) Evaluation of Biofeedback in Lumbar Orthoses.** *Malcolm H. Pope, PhD.* Lumbosacral corsets are frequently prescribed for low back pain, although their effectiveness and mechanism of action have not been demonstrated. The project compares the effectiveness of auditory feedback, trunk inclination feedback, and EMG feedback; the project comprises design and testing of devices and two triple crossover studies.

**6) Seating Studies.** *Steven Reinecke, MSME.* A prototype lordotic CPM device has been designed; when incorporated in a typical office chair, it provides continuous motion in the lumbar region. The device is now being tested to determine its efficacy in minimizing back discomfort in both static and vibrational seating environments. An adjustable sit-stand work station has also been designed and is being tested to assess its effect on subject fatigue, comfort, and productivity.

**7) Vibration Studies.** *David Wilder, PhD.* With a long-range goal of optimizing work environments that involve vibration, this project concerns the relative contributions of various spinal support



structures, seating components, and postures. Worksite assessments are frequently performed to measure amounts of vibration and impact, and recommendations are made to minimize their deleterious effects on the spine.

**8) Development of a Workload Assessment System.** *Jerry Weisman, MSME.* A Workload Assessment System is being developed to provide detailed information about various biomechanical stresses in the workplace. Posture and load can be monitored continuously over the course of the day and analyzed to provide a picture of job task demands. The system will be evaluated in numerous occupational settings in Vermont and elsewhere.

**9) Information Services: Publications.** *Antonia Clark, MS. Public Relations. Janice Clements, BS.* The REC's Information Services Division comprises numerous information and referral activities. Work is underway to construct a national knowledge repository, including a comprehensive bibliographic database and service directory. The Vermont REC offers assistance in locating research, treatment, and rehabilitation programs.

#### Recent Publications Resulting from This Research

**Internal Displacement Distribution from In Vitro Loading of Human Lumbar Spinal Motion Segments: Experimental Results and Theoretical Predictions.** Krag MH, Seroussi RE, Wilder DG, Pope MH, *Spine* 12(10):1001-1007, 1987.

**Predictors of Low Back Pain Disability.** Frymoyer JW, Cats-Baril WL, *Clin Orthop* 221:89-98, 1987.

**Back Pain and Sciatica.** Frymoyer JW, *N Engl J Med* 318(5):291-300, 1988.

**The Biomechanics of Lumbar Disc Herniation and Effect of Overload and Instability.** Wilder DH, Pope MH, Frymoyer JW, *J Spinal Disord* 1(1):16-32, 1988.

**Concepts in the Prevention of Low Back Pain.** Pope MH, *Contemp Orthop* 17(3):43-54, 1988.

**Identifying Patients at Risk of Becoming Disabled Due to Low Back Pain: The Vermont Rehabilitation Engineering Center Predictive Model.** Cats-Baril WL, Frymoyer JW, *Annual Meeting of the Eastern Orthopaedics Association*, Dorado Beach, Puerto Rico, 1988.

**An Internal Fixator for Posterior Applications to Short Segments of the Thoracic, Lumbar, or Lumbosacral Spine: Design and Testing.** Krag MH, Frymoyer JW, Beynnon BD, Pope MH, in *Lumbar Spine Surgery: Techniques and Complication*, A.H. White, R.H. Rothman, R.C. Ray (Eds.), St. Louis: C.V. Mosby Co., 1988.

**Isokinetic Trunk and Lifting Strength: Variability as an Indicator of Effort.** Hazard RG, Reid S, Fenwick J, Reeves V, *Spine* 13(1):43-47, 1988.

**Morphometry of the Thoracic and Lumbar Spine Related to Transpedicular Screw Placement for Surgical Spinal Fixation.** Krag MH, Weaver DL, Beynnon BD, Haugh LD, *Spine* 13(1):27-32, 1988.

**Neuropharmacologic Effects of Vibration on the Dorsal Root Ganglion.** Weinstein J, Pope MH, Schmidt R, Seroussi R, *Spine* 13(5):521-525, 1988.

**Reproducibility of Four Clinical Methods for Assessment of Lumbar Spinal Motion.** Gill K, Krag MH, Johnson GB, Haugh LD, Pope MH, *Spine* 13(1):50-53, 1988.

**Segmental Instability.** Frymoyer JW, Pope MH, Wilder DG, in *The Lumbar Spine*, J. Weinstein, M. Tile (Eds.), Toronto: ISSLS, 1988.

**Functional Restoration with Behavioral Support: A One-Year Prospective Study of Patients with Chronic Low Back Pain.** Hazard RG, Fenwick JW, Kalisch SM, Redmond J, Reeves V, Reid S, Frymoyer JW, *Spine* 14(2):157-161, 1989.

**New Perspectives on Low Back Pain.** Frymoyer JW, Gordon SL, *American Academy of Orthopaedic Surgeons*, Park Ridge, IL, 1989.

**Rehabilitation Technology in the Workplace.** Weisman J, in *CRC Handbook on Rehabilitation Engineering*, Boca Raton: CRC Press, 1989.

**Trunk Muscle Electromyography and Whole Body Vibration.** Seroussi RE, Wilder DG, Pope MH, *J Biomech* 22(3):219-229, 1989.

**Internal Deformations of Intact and Denucleated Human Lumbar Discs Subjected to Compression, Flexion and Extension.** Seroussi RE, Krag MH, Muller DL, Pope MH, *J Orthop Res* (in press).

## D. Vascular Disorders

### [393] Benzodiazepine Therapy in Improving Glucose Metabolism in Non-Insulin Dependent Diabetes Mellitus

**Richard S. Surwit, PhD**

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**Sponsor:** *Duke University Medical Center; National Institutes of Health*

**Purpose**—This study will explore the efficacy and mechanism of progressive relaxation training and benzodiazepine therapy in improving glucose metabolism in non-insulin dependent diabetes mellitus (NIDDM).

**Methodology**—Fifty NIDDM patients will participate in two experiments sequentially. In the first experiment, patients will receive a glucose tolerance test, an insulin tolerance test, an epinephrine sensitivity test, and a psychometric assessment. Random subjects will receive benzodiazepine or placebo; 8 weeks later blood glycohemoglobin will be measured. The drug condition of the patients will be reversed at this time.

Four weeks following the termination of the drug study, patients will be readmitted to the hospital. At that time, the glucose tolerance test will be re-performed. The patients will be randomly assigned to control or treatment conditions: 1) progressive relaxation with compliance enhancement instructions; and, 2) no behavioral treatment.

**Preliminary Results**—Relaxation training can provide a significant improvement in glucose tolerance in some patients with NIDDM. This improvement is distinct from improvements in fasting blood glucose and glycohemoglobin which are observed to occur with dietary therapy and oral medication.

**Future Plans/Implications**—The investigators observed that relaxation significantly affects average

daily blood glucose or glycohemoglobin. Although epinephrine will raise fed but not fasting glucose values and relaxation will improve fed but not fasting values, effects of relaxation on chronic measures of glucose control (average daily glucose and glycohemoglobin) might be optimized if the patients were specifically instructed to practice relaxation after meals at home. The investigators, therefore, will test the efficacy of two schedules of relaxation with respect to meals on chronic measures of glucose control. They will also examine whether stress has differential effects on glucose metabolism in the fed and fasted state.

#### Publications Resulting from This Research

**The Effects of Relaxation Therapy on Patients with Type I Diabetes Mellitus.** Feinglos MN, Hastedt P, Surwit RS, *Diabetes Care* 10:72-75, 1987.

**Type A Behavior Pattern and Blood Glucose Control in Diabetic Children.** Stabler B, Surwit RS, Lane JD, Morris MA, Litton J, Feinglos MN, *Psychosom Med* 49:313-316, 1987.

**Diet Induces Type II Diabetes in Normal C57BL/6J Mice: A New Animal Model.** Surwit RS, Kuhn CM, Cochrane C, McCubbin JA, Feinglos MN, *Diabetes* 37:1163-1167, 1988.

**Psychological Predictors of Glucose Control in Patients with Insulin-Dependent Diabetes Mellitus.** Lane JD, Stabler B, Ross SL, Morris MA, Litton JC, Surwit RS, *Diabetes Care* 11:798-800, 1988.

**Stress and Autonomic Nervous System in Type II Diabetes Mellitus: A Hypothesis.** Surwit RS, Feinglos MN, *Diabetes Care* 11:83-85, 1988.

**Differential Glycemic Effects of Morphine in Diabetic and Normal Mice.** Surwit RS, McCubbin JA, Kuhn CM, Cochrane C, Feinglos MN, *Metabolism* 38(3):282-285, 1989.



### [394] Longitudinal Study of Insulin-Dependent Diabetics

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**Sponsor:** *National Institutes of Health; University of Pittsburgh*

**Purpose**—This is an ongoing longitudinal study of 8- to 13-year-old children with insulin-dependent diabetes who have been followed since the diabetes was diagnosed. The study objectives include: 1) establish the incidence of depression as an initial response to later sequelae of diabetes; 2) test the hypothesis that an initial depressive reaction is akin to “mourning” and a good prognosticator of later adjustment; 3) examine over time the interface of psychosocial and medical variables; 4) delineate the characteristics of coping; 5) delineate predictors of poor metabolic control; 6) test the hypothesis that adolescents have unique problems, increased psychiatric illness, and worsening of metabolic control; 7) examine precursors of adolescent adjustment and medical status; and, 8) delineate the psychologic/functional impact of the onset of diabetic complications.

**Methodology**—The project entails a repeated assessment design with 95 newly diagnosed juvenile diabetics and their parents. These 95 children were entered into the study during May 1978 through September 1985.

**Results**—Selected findings to date follow:

*Intellectual and academic development.* Over time, there are incremental performance deficits on a measure of verbal intelligence and an index of academic achievement.

*Psychologic adjustment.* Cross-sectional analyses of intake self-report scales revealed low levels of emotional symptoms and good self-esteem, which were not affected by gender, or age-at-onset, or duration of diabetes.

*Psychiatric disorders.* In apparent contradiction to the picture of self-perceived psychologic stability, depressive disorders are the most prevalent psychiatric outcomes.

**Future Plans/Implications**—The young diabetic and parents may derive some comfort from being able to verbalize topics of concern and from having someone listen to their feelings and opinions. Although the clinical interviews are research oriented, sympathetic listening and understanding may have therapeutic effects. Additionally, some families have verbalized a sense of pride and satisfaction in being able to contribute to a better understanding of the psychosocial sequelae of diabetes.

Furthermore, the study has and will continue to facilitate identification of those youth who need psychological/psychiatric referral and care. In some instances where this need arose, the child's medical management was also enhanced, because the information was provided to the child's physician who took the appropriate stance vis-a-vis contacts with the family.

The findings may lead to a more systematic understanding of the range of psychosocial sequelae of insulin-dependent diabetes and their relationship to the course of the disease. Appropriate and intelligent use of such research data may lead to decisions that can improve the diabetic child's care and quality of life.

#### **Publications Resulting from This Research**

None reported.

### [395] Non-Septic Tarsal Disintegration in Leprosy

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Sponsor: Poona District Leprosy Committee

**Purpose**—During the study conducted on tarsal disintegration (TD) at our institution, we came across two distinct groups of cases: 1) one group had changes of TD without the history of ulcer or sepsis; and, 2) the other group had frank sepsis with TD. The purpose of this study was to find the clinical presentation and the precipitating factors responsible for the onset of this non-septic variety of TD.

Tarsal disintegration, a specific entity occurring in the neuropathic foot of leprosy, comprises a series of slow progressive changes, where the tarsal bones lose their anatomical configurations and gradually proceed to disorganization. It has already been proved that increased and abnormal shearing forces occurring during the heel-toe pattern are the main causative factors both in occurrence and progression of TD.

**Progress**—Forty patients (12 to 65 years old) with the non-septic variety of TD were studied. There were four bilateral cases—one with sepsis and the others without. There were ten cases with the tuberculoid variety of the disease, 25 of borderline tuberculoid, three of borderline lepromatous, one of pure lepromatous, and one of secondary polyneuritic variety. There was no history of ulcers, and only two patients had a history of a sprained ankle. Clinical manifestations comprised: 1) swelling and raised temperature around the talonavicular junction; 2) bony crepitus; 3) intrinsic muscle paralysis; 4) collapsed medial longitudinal arch; and, 5) disorganized malleolar and talonavicular anatomical configurations.

Only four patients had foot-drop prior to developing TD. Six patients underwent surgery for foot-drop at other centers: however, TD was under control when they reported to our institution.

Deep sensation testing could be performed only in eight patients. Superficial sensation and joint position sense was totally lost in all these patients. All of them had higher vibratory threshold values

when compared with the unaffected leg. The majority of the patients showed common radiological changes (medial pillar involvement) in the form of squeezing or fragmented navicular absorbed head neck with a flattening and tilting of the talus.

Two patients showed hind and forefoot separation. None of the patients had used specialized footwear prior to reporting to this institution and walked either barefoot or with ordinary footwear on swollen ankles.

**Results**—Tarsal disintegration changes were seen predominantly in the borderline tuberculoid variety of leprosy. Out of 40 patients, only four had foot-drop prior to developing TD. Extrinsic paralysis did not seem to be the precipitating factor for this process. Hasty and unsupervised weightbearing was the reason given by a few patients who had been immobilized because of a sprained ankle. It is therefore suggested that gradually-graded weightbearing must be instituted in patients who are either immobilized or confined to bed for long periods due to illness, or for a short term cause like a sprain. The process must be controlled before a patient submits to foot-drop surgery. One patient who underwent a foot-drop correction reported ankle swelling pre-operatively.

Radiological involvement was more confined to medial pillar. This was unlike the septic variety of TD which showed gross radiological changes in the form of ankle mortise involvement, ectopic calcifications, saucerization, and splits in calcaneum. Superficial sensory testing showed a direct correlation with the process of disintegration. However, the loss of deep sensation did not seem to have any predictive value.

All these cases had significantly higher vibratory threshold values, but all cases having higher vibratory threshold need not have TD. This was observed in a separate study where 40 percent of the patients who did not have ulcers and showed no



signs of TD, had abnormal vibratory threshold values.

#### Publications Resulting from This Research

None reported.

### [396] Microcomputer-Based Program for Studying Low Back Pain

**S.P.F. Hughes; H.T. Law; R.D. Bagnall**

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*Sponsor: Scottish Home and Health Department*

**Purpose**—The purpose of this study was to write a program for the BBC microcomputer in three sections: 1) patient history, distribution and duration of symptoms, alleviating and aggravating factors; 2) clinical examination and findings, completed by the clinician immediately following the examination; and, 3) results of laboratory tests and other diagnostic procedures.

**Methodology**—The program throughout is menu driven, with simple on-screen instructions. The microcomputer is situated in the clinical examination room and this part of the examination can usually be entered into the machine by the patient, after a short demonstration of what is required, or can be completed by the physician during the course of the history taking.

Each patient is allocated a diskette (5.25 inch) on first attendance at the clinic, and this is used on all subsequent visits. There is provision for assigning flags

to the records to identify the type of treatment adopted. The records can be used to write a hard copy for inclusion in the patient notes; write a letter to the patient's general practitioner or referring physician; inspect past records to compare; and test, by statistical processes, the results of the treatment adopted.

**Preliminary Results**—The software development has taken approximately 1 year and the first system has been installed in the clinic for 2 months. A growing database is now being accumulated, but it is too early to state whether the latter objective is adequately achieved. It has already been shown to be a time saving and effective means of recording the various aspects of a chronic orthopedic condition and should provide an improved means of retrospective comparative evaluation.

#### Publications Resulting from This Research

None reported.

### [397] Heart and Vascular Diseases Program: Preventive Cardiology Academic Awards

**Dennis M. Davidson, MD; Ira S. Ockene, MD**

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*Sponsor: National Heart, Lung, and Blood Institute, National Institutes of Health*

**Purpose**—The National Heart, Lung, and Blood Institute provides leadership for a national program in diseases of the heart, blood vessels, lungs, and blood, and in the uses of blood and the management of blood resources.

The Institute's program of research related to rehabilitation addresses in general terms the rehabilitation of coronary heart disease patients after a myocardial infarction (MI) or in the post-operative phase after coronary artery bypass graft surgery,

patients with chronic obstructive pulmonary and lung diseases, and the prevention of post-operative thromboembolism in surgical patients.

Two Preventive Cardiology Academic awardees of the National Heart, Lung, and Blood Institute's Heart and Vascular Diseases Program have included rehabilitation activities in their programs. One study involves the observation of abnormal responses in exercise testing of cardiovascular patients. The other study, involving fourth-year medical students in a

hospital Physical Medicine and Rehabilitation Department, includes education programs to modify the recurrence of cardiovascular events.

#### **Publications Resulting from This Research**

**Attitudes Toward Prevention of Cardiovascular Diseases Among First-Year Students at Eight American Medical Schools.** Greenland P, Castle C, Cohen JD, Davidson DM,

Krakoff LR, Nowacek G, Pearson TA, Riemenschneider TA, Van Clitters RL, Stone EJ, *Prev Med* 17:700-711, 1988.

**FACSM Estimating VO<sub>2</sub> Max from a Modified Balke Treadmill Protocol: Validation in a Young Healthy Population.** Frid D, Ellefsen K, Porcari J, Ward A, Ockene IS, Rippe J, *Med Sci Sports Exerc* 20(2 Suppl):S1, 1988.

**Outpatient Versus Inpatient Cardiac Catheterization.** Block PC, Ockene IS, Goldberg RJ, Butterly J, Block EH, Degon C, Beiser A, Colton T, *N Engl J Med* 319(19):1251-1255, 1988.

### **[398] Exercise Training for Rehabilitation of Coronary Heart Disease Patients**

**Albert Oberman, MD**

University of Alabama, Birmingham, AL 35294

**Sponsor:** *National Heart, Lung, and Blood Institute, National Institutes of Health*

**Purpose**—This study compares the effects of low and high levels of regular supervised training over a 2-year treatment period on cardiac adaptations among 200 patients with coronary heart disease (CHD) documented by arteriogram or with clinical documentation of myocardial infarction (MI). Supine ergometer exercise and upright maximal exercise testing with gas exchange measurements will be

done periodically. Both tests include two-dimensional echocardiography. Change in exercise ejection fractions at 1 year will be evaluated. The study has implications for exercise prescriptions and patient evaluation in cardiac rehabilitation programs.

#### **Publications Resulting from This Research**

None reported.

### **[399] Smoking Cessation in Patients with Cardiovascular Disease**

**Craig Taylor, MD; Judith Ockene, PhD; George Bigelow, PhD; Jeffrey Levenkron, PhD; Virginia Rice, PhD; Kenneth Wallston, PhD**

Stanford University Medical School, Stanford, CA 94305; University of Massachusetts Medical School, Worcester, MA 01605; Johns Hopkins University, Baltimore, MD 21218; University of Rochester, Rochester, NY 14627; Wayne State University, Detroit, MI 48202; Vanderbilt University, Nashville, TN 37203

**Sponsor:** *National Heart, Lung, and Blood Institute, National Institutes of Health*

**Purpose**—As many as 70-to-80 percent of individuals who smoke and have a coronary event resume smoking after the event. The goals of this program are to develop and evaluate interventions to meet the needs of such individuals in achieving long term smoking abstinence. Six grants are nearing completion. The studies include a randomized trial comparing special interventions (self-help materials and intervention telephone calls, group sessions, and newsletters) with an advice-only intervention.

**Preliminary Results**—It was found that social support has more effect on smoking abstinence than do

antismoking information and external rewards. Preliminary analysis in another study showed that myocardial infarction patients were more successful in maintaining smoking cessation for 3 months than were patients with peripheral vascular disease. In a third study, patient attendance at a class in the hospital was so poor that this educational method was abandoned and a telephone counseling service, which reached many more patients, was instituted.

#### **Publications Resulting from This Research**

None reported.



## [400] Effects of Social Support on Recovery from Coronary Artery Bypass Graft Surgery

**Kathleen King, BS**

University of Rochester, Rochester, NY 14627

**Sponsor:** *National Heart, Lung, and Blood Institute, National Institutes of Health*

**Purpose**—The purpose of this study is to enhance understanding of how different types of social support affect patients and their spouses following coronary bypass graft surgery. The objectives are to identify different types and sources of social support and to relate the types of support to health outcome

and spouses' psychological functioning. Data are being collected by interview within a short time prior to surgery and at 1, 4, and 12 months afterward.

### **Publications Resulting from This Research**

None reported.

## [401] Approaches to Rehabilitation in Chronic Lung Disease

**Steven G. Kelsen, MD**

Temple University, Philadelphia, PA 19122

**Sponsor:** *National Heart, Lung, and Blood Institute, National Institutes of Health*

**Purpose**—Within the context of a comprehensive rehabilitation program, this study seeks to examine the relative effect of specific respiratory muscle training and general body exercise reconditioning on respiratory muscle strength and endurance, exercise capacity, and psychological and nutritional status.

Eighty subjects with advanced chronic obstructive lung disease have been screened for possible inclusion in the study.

### **Publications Resulting from This Research**

None reported.

## [402] Self-Management Education for Adults with Asthma

**Sandra Wilson, PhD**

American Institute for Research, Palo Alto, CA 94305

**Sponsor:** *National Heart, Lung, and Blood Institute, National Institutes of Health*

**Purpose**—This study is an evaluation of the various approaches used in the education of adults with asthma and in the identification of the types of patients for whom certain approaches are most cost-effective. The results may be useful in adapting effective educational programs to a variety of settings. Data collected from patients over a 2-year period will be evaluated to determine if any changes have occurred in lung function, asthma symptoms,

use of health care services, or other indicators of the state of the patient's asthma.

### **Publications Resulting from This Research**

**An Evaluation of Approaches to Asthma Self-Management Education for Adults: The AIR/Kaiser Permanente Study.** Wilson-Pessano S, Scamagas P, Arsham GM, Chardon L, Coss S, German DF, Hughes GW, *Health Ed Q* 14(3):333-343, 1987.

### [403] Randomized Trial of Rehabilitation in Chronic Obstructive Pulmonary Disease

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**Robert M. Kaplan, PhD**

University of California, La Jolla, CA 92093

**Sponsor:** *National Heart, Lung, and Blood Institute, National Institutes of Health*

**Purpose**—This project is evaluating the effectiveness of a comprehensive pulmonary rehabilitation program consisting of an educational component, physical and respiratory care, psychosocial support, and exercise training. At 1 year patient follow-up exercise endurance was increased substantially and the number of physician and emergency room visits was

reduced. The cost implications of this program also are being evaluated.

#### **Publications Resulting from This Research**

**Experimental Evaluation of Rehabilitation in Chronic Obstructive Pulmonary Disease: Preliminary Results on Exercise Tolerance and Health Status Outcomes.** Toshima MT, Kaplan RM, Ries AL, *Health Psychol* (in press).

### [404] Post-Operative Thromboembolism in Surgical Patients

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**Edwin W. Salzman, MD**

Beth Israel Hospital, Boston, MA 02215

**Sponsor:** *National Heart, Lung, and Blood Institute, National Institutes of Health*

**Purpose**—In this clinical trial, a hemodynamically optimized system for external pneumatic compression of the lower limbs to prevent venous thrombosis is being used in patients undergoing neurosurgical procedures.

graded sequential device developed a postoperative increase in blood fibrinolytic activity, possibly explaining the decreased incidence of thrombosis. This increase was not seen in those patients treated with the uniform compression systems.

**Results**—External pneumatic compression represents a less invasive approach to the prophylaxis of deep vein thrombosis, and to date, it appears that the graded sequential system is superior to two uniform compression systems. Most patients treated with the

#### **Publications Resulting from This Research**

**Effect of Optimization of Hemodynamics on Fibrinolytic Activity and Antithrombotic Efficacy on External Pneumatic Calf Compression.** Salzman EW, McManama GP, Shapiro AH, Donovan AS, Blume HW, Sweeney J, Kamm RD, Johnson MC, Black PM, *Ann Surg* 206:63, 1987.

### [405] Basic and Clinical Studies of Coagulation Proteins

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**Victor J. Marder, MD**

University of Rochester, Rochester, NY 14627

**Sponsor:** *National Heart, Lung, and Blood Institute, National Institutes of Health*

**Purpose**—A subproject of this clinical study compares the safety and efficacy of external compression to warfarin in the prevention of postoperative thromboembolic disease following total hip replacement. Warfarin is an established, effective prophylaxis against deep vein thrombosis in the setting of cemented total hip replacement, but its general use

has been hindered by a perceived risk of increased bleeding complications. This study will determine whether the safer application of external pneumatic compression is as effective as warfarin anticoagulation in prophylaxis after noncemented total hip replacement.



**Preliminary Results**—Preliminary observations indicate that thromboembolic diseases in patients receiving noncemented prostheses is lower than in those receiving cemented prostheses.

#### **Publications Resulting from This Research**

**Long Term Clinical Findings and Venous Functional Abnormalities After Asymptomatic Total Hip and Knee Replacement.** Francis CW, Ricotta JJ, Evarts CM, Marder VJ, *Clin Orthop* 232:271, 1988.

## XIII. Head Trauma and Stroke

*For additional information on topics related to this category see the following Progress Reports: [82], [232], [265].*

### [406] Central Motor Tract Testing After Recently Completed Stroke

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**Pravin D. Panchal, MD; Lawrence R. Robinson, MD**  
VA Medical Center (UD), Pittsburgh, PA 15240

**Sponsor:** VA Rehabilitation Research and Development Service (Project #B453-RA)

**Purpose**—The purpose of this study was to measure central motor conduction time (CMCT) in both stroke patients and controls and to assess the prognostic value of this measure by attempting to predict rehabilitative success of stroke patients.

Our initial plan was to examine whether CMCTs correlate with other measures of motor function by using age-matched controls. We would then conduct a prospective study of stroke patients by measuring CMCT, strength, and disability scores at 1 and 5 weeks, and later to attempt to predict outcomes of stroke patients.

**Methodology**—The descending motor fibers of the motor cortex are stimulated by using a large, short

duration magnetic field. The time between stimulation and the resultant muscle action potential provides a measure of the CMCT.

**Results**—This project has been terminated because the anticipated Federal Drug Administration (FDA) approval of the cortical magnetic stimulator (CMS) coil has not been forthcoming. It is currently uncertain when, if ever, FDA approval would be given. The vendor supplying the instrumentation has not produced a commercial version of the CMS coil.

#### **Publications Resulting from This Research**

None reported.

### [407] Effects of Thermal Stimulation on Dysphagia After Stroke

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**John C. Rosenbek, PhD**

Audiology and Speech Pathology Service, William S. Middleton Memorial VA Hospital, Madison, WI 53705

**Sponsor:** VA Rehabilitation Research and Development Service (Project #C485-RA)

**Purpose**—This project was designed to measure the effects of thermal stimulation on impaired swallowing after stroke.

**Methodology**—Patients with clinical and imaging evidence of multiple cerebral vascular accidents (CVAs) and delays in the pharyngeal response during liquid swallows (as confirmed by video-fluoroscopy) were enrolled in this study. This investigation used a modified withdrawal design for matched pairs with replication across 20 patients. Following the baseline studies, patients were randomly assigned to either an ABAB or BABA pattern of experiments. "A" signifies a period of no stim-

ulation; "B" signifies a period of thermal stimulation. All patients underwent 1-month follow-up.

Fluoroscopic data were analyzed visually and with a visual image processing program (Swallowing/Speech Interactive Image Processing Program [SIP]).

**Results**—Twelve patients have been studied. Data from 7 of these patients are being analyzed; data from the next 5 patients are being prepared for analysis.

#### **Publications Resulting from This Research**

None to date.



## [408] Assessment of Motor Control in Stroke Patients

**T. Sciascia; G. Kamen; C.J. DeLuca**

VA Outpatient Clinic and Hospital, Boston, MA 02108; NeuroMuscular Research Center, Boston University, Boston, MA 02215

**Sponsor:** *VA Rehabilitation Research and Development Service; Liberty Mutual Insurance Company*

**Purpose**—The vestibular apparatus of the inner ear acting via the vestibulospinal tract is known to influence postural muscle tone as well as the level of excitability of motor neurons during muscular contractions. This work is an attempt to demonstrate a supraspinal modulation of the motor control properties governing muscular activity in humans. In addition, the study will also provide useful control data for the analysis of muscle contraction abnormalities found in patients who have suffered a stroke. We will study the clinical neurophysiology of muscle weakness and spasticity found in humans after a stroke. The study will focus on quantifying

abnormalities of motor control obtained in a recording session with the degree of spasticity and weakness found in clinical examinations and anatomical findings on CAT scan. The vestibular system is a major supraspinal determinant of the hemiplegic posture once cortical influences are altered or abolished in stroke. Caloric stimulation performed on these patients to monitor vestibular effects on motor control will be compared to the control data obtained from normal subjects.

### **Publications Resulting from This Research**

**None reported.**

## [409] Studies of Anticipatory Behavior Deficit

**Joseph Bleiberg; Alyson M. Muff**

The National Rehabilitation Hospital, Washington, DC 20010

**Sponsor:** *Centers for Disease Control*

**Purpose**—The purpose of our current research was two-fold: 1) to use the anticipatory behavior deficit (ABD) to extend our understanding of the consequence of closed head injury (CHI) in patients with mild to moderate levels of injury severity. Deficits in planning and anticipation are highly prevalent following frontal lesions. Since CHI patients typically have greater frontal and subfrontal involvement than do other brain-injured patients, the ABD task should be sensitive to both the presence and severity of frontal lobe injury; and, 2) to investigate the practical usefulness of the ABD paradigm as an assessment tool to aid in the design of cognitive rehabilitation for individuals with CHI.

**Methodology**—The subjects used in the ABD pilot were categorized by injury status (uninjured and nonfocal traumatic brain injury patients of mild and moderate severity). Trauma patients diagnosed as having CHI were categorized as to severity using

objective selection criteria such as admission Glasgow Coma Scale scores and loss of consciousness (time). A number of exclusion criteria known to influence CHI performance (drug use, previous head injury) were used to control for external interference with performance.

**Progress**—We have developed a computerized version of the ABD task which allows for the dissemination of the task to widespread clinical and research-oriented audiences. Moreover, we have completed a pilot study using the computerized version of the ABD task with CHI and normal subjects. Currently, we are engaged in developing a sophisticated database that will allow us to obtain reliability estimates of the task and its predictive validity.

**Results**—The results of the pilot study (N=30), which used the computerized version of the ABD



task, replicated those findings associated with past ABD studies. The replication of previous results suggests that the newly developed computerized ABD task is a tenable measure for assessing the presence or absence of ABD in CHI subjects.

**Future Plans/Implications**—Future plans for the ABD task include: 1) the complete psychometric development of the ABD task in order to meet psychometric standards for use as a clinical assessment instrument; and, 2) the construction of a

sophisticated database which will allow for the investigation of relationships between ABD, real life functions, and neuropathological variables of interest.

#### Publications Resulting from This Research

**Anticipatory Behavior Deficits in Closed Head Injury.** Freedman PE, Bleiberg J, Freedland K, *J Neurol Neurosurg Psychiatr* 50:398-401, 1987.

**Neuropsychological Test Correlates of Anticipatory Behavior Deficit in Closed Head Injury.** Rothke S, Bleiberg J, Freedland K, *Int J Clin Neuropsychol* 9(2):81-83, 1987.

### [410] An Interactive Computer Program to Assess and Facilitate Cognitive Function in Head-Injured Young People

Pat Johnson, PhD, SpEd; Nancy Thomas-Stonell, BScDSP, CCC-Sp, Reg OSLA; Laurie Scott, MS, S-LP(C), CCC-Sp, Reg OSLA; Stephen Naumann, PhD, PEng; Fraser Shein, MEng, PEng; Geb Verburg, MA  
Hugh MacMillan Medical Centre and Hugh MacMillan Centre School, Toronto, Ontario M4G 1R8 Canada

**Sponsor:** *Easter Seal Research Institute; Apple Canada; Hospital for Sick Children Foundation*

**Purpose**—The purpose of this study is to develop and evaluate a microcomputer-based system for assessing and training language skills in cognitively-impaired young people. Specific goals are to: 1) develop an interactive computer program incorporating voice input and output technology for the assessment and remediation of cognitive-related language deficits in head-injured patients; and, 2) evaluate the effectiveness of this program for remediating the skill areas of attention, comprehension, memory and word retrieval, organization, reasoning, and problem solving.

**Methodology**—The first year of the project will focus on the development of the computer program, whose format will resemble an adventure game. A prototype of the program will be introduced to head-injured individuals to establish its appeal and functionality. During the second year, the program will be pilot-tested with a minimum of 10 head-injured subjects. In an Awithin-subject design, each subject will act as his or her own control. A standardized assessment battery will be administered to establish a baseline measure. Twelve weeks later, the battery will be readministered to measure the extent of spontaneous recovery. Results from the

standardized assessment battery will be compared with those obtained from the assessment module of the software. A 12-week remediation program will follow. Upon completion of the remediation program, a third test session will evaluate the effectiveness of the training. The computer will collect data specific to the adventure game program during the remediation phase. These data will be analyzed for improvement over time. Software tools used for this project include Course Builder, MacRecorder, and a new voice recognition program.

**Preliminary Results**—The project is in the development phase. Two sections of the adventure game program are being implemented: an assessment module and a remediation module. The assessment module is nearing completion. Segments of it are currently being tested and revised as needed. The remediation module has been designed and initial development has begun. Its completion is expected by the end of the first year of the project. Once the modules are finished, the clinical testing phase of the project will begin.

#### Publications Resulting from This Research

None reported.



## [411] Quantification of Motor Coordination of the Lower Limb in Normal and Hemiparetic Subjects

**Daniel Bourbonnais, PhD; Denis Gravel, MSc; A. Bertrand Arsenault, PhD**  
Research Center of the Institut de Réadaptation de Montréal, Montréal, Quebec H3S-2J4 Canada

**Sponsor:** Medical Research Council of Canada; Fonds de la Recherche en Santé du Québec; Department of Health and Welfare

**Purpose**—We have developed a dynamometer that measures torques exerted simultaneously in different anatomical planes of the hip and knee (flexion/extension, abduction/adduction, internal/external rotation of the hip, and flexion/extension of the knee). Using this apparatus in a task control situation, we now plan to quantify and compare torques and muscle activation patterns occurring in hemiparetic subjects and normal subjects. It is hoped that this approach will be useful as a tool for evaluating motor dysfunction in hemiparetic subjects.

**Methodology**—Subjects are seated and their lower limbs are secured to the dynamometer. Assessment is based upon measurement of adequate lever arms and of orthogonal forces exerted at the thigh and calf level. Strain gauges are interfaced to a desktop computer in order to calculate values for multi-planar torques (flexion/extension, abduction/adduction, internal and external rotation at the hip; and flexion/extension at the knee) in real time. A monitor is used to display the direction and magnitude of the subject's effort at a specific joint.

During a typical experiment, subjects are asked to perform specific efforts at 10 percent and 30 percent of the maximal voluntary contraction (MVC). This MVC is measured on the unaffected side of hemiparetic subjects and on both sides of normal subjects. Electromyographic activities and torques in the different muscles of the lower limb are measured concurrently. As the experiment progresses, subjects are asked to control torques exerted in an increasing number of planes of movement (e.g., flexion of the hip, flexion/adduction of the hip, flexion/adduction/internal rotation of the hip). This will require coordinated muscle activation patterns in order to achieve the appropriate combination of torques. Clinical evidence has suggested that the movement repertoire of hemiparetic subjects consists of stereotypical torque patterns. The present study will characterize and

compare these stereotypical patterns and associated muscle activation patterns in hemiparetics with those of normal subjects.

**Progress**—Validity of the dynamometric measurements has been established using a mechanical leg that generates specific torques at single or both joints. The discrepancy between imposed torques and readings from the dynamometer is less than 2 percent indicating that the dynamometer is precise. Moreover, the dynamometer reads specific torques, since less than 2 percent of the imposed torques is measured in planes other than that of the required movement.

We have developed software to control the task and to analyze the data. Electromyographic activities are summarized by polar plots, while torque patterns are represented by histograms.

**Future Plans**—The apparatus we developed can now be used in a wide range of electromyographic, biomechanical, and clinical studies. For example, the contributions of bi-articular muscles to movement performance will be studied by imposing specific, or combinations of torques, at the hip and knee. In addition, it will eventually be possible to use the methodology described above as an evaluation tool or as a treatment modality in clinical studies of stroke patients.

### Publications Resulting from This Research

**Abnormal Patterns of Elbow Muscle Activation in Hemiparetic Subjects.** Bourbonnais D, Vanden-Noven S, Carey KM, Rymer WZ, *Brain* 112:85-102, 1989.

**Conception d'un Dynamomètre Bi-Articulaire du Membre Inférieur.** Bourbonnais D, Gravel D, Arsenault AB, Duval P, Goyette M, in *Proceedings of the Canadian Medical and Biological Engineering Society*, Toronto, 145-146, 1989.

**Weakness in Patients with Hemiparesis.** Bourbonnais D, Vanden-Noven S, *Am J Occup Ther* 43:313-319, 1989.

**A Dynamometer Measuring Torques Exerted Statically at the Hip and Knee.** Bourbonnais D, Gravel D, Arsenault AB, Steele C, Duval P, Goyette M, Abstract presented at the 13th Annual Meeting of the American Society of Biomechanics (in press).



## [412] Model System for Minimizing Disability After Head Injury

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The Institute for Rehabilitation and Research, Houston, TX 77030

Sponsor: *National Institute on Disability and Rehabilitation Research*

**Purpose**—Our purpose is to: 1) demonstrate and evaluate a comprehensive model service delivery system for individuals with traumatic brain injury (TBI), including the evaluation and analysis of costs and benefits of such a system of care; 2) establish a research program to develop new information and conduct innovative analyses of data; 3) demonstrate and evaluate the development and clinical application of improved methods essential to the care and rehabilitation of individuals with traumatic brain injury; and, 4) participate in national studies of the TBI Model System by contributing to a national database as developed and coordinated by the National Institute on Disability and Rehabilitation Research.

**Progress**—During the 7 months covered by this progress report we have: 1) participated in a pilot test of data collection feasibility; 2) proposed revisions to the National TBI Database Coding Forms based on our experiences in using them; 3) established a procedure for follow-up of patients discharged from the inpatient program; 4) developed a procedure for obtaining financial information about patients receiving rehabilitation at The Institute for Rehabilitation and Research (TIRR); 5) entered data on 39 patients into the TIRR Head Injury database; 6) proposed to the other four Model TBI Systems and the Rehabilitation Research and Training Cen-

ter—TBI, SUNY Buffalo that we consider using the software "Paradox" on IBM-compatible PCs of the AT type for managing the National TBI Database at each collaborating center; 7) proposed revisions to the battery of neuropsychological tests being considered for adoption by the five Model TBI Systems; 8) entered into a collaborative study with the NYU Research and Training Center on Head Injury and Stroke to provide data from the Head Injury Family Interview; 9) established a procedure for holding "rounds" on patients with head injury being cared for in our collaborating acute care facility; 10) prepared a *Family Education Manual on Head Injury*; 11) revised the *Glossary of Terms of Interest to Persons in the Field of Head Injury*; 12) participated in the development of a local special interest group for Computer Users with Physical Disabilities within the Houston Area League of PC Users, Inc.; 13) participated in Model Systems TBI Database Collection Training Session in Richmond, VA; and, 14) prepared a position description of the Head Injury Program Nurse who will be instrumental in collecting data on patients with mild and moderate head injury presenting to the emergency room of our collaborating trauma center.

### Publications Resulting from This Research

None reported.

## [413] Model Family Professional Partnership Interventions for Child Traumatic Brain Injury Survivors

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Sponsor: *National Institute on Disability and Rehabilitation Research (The New York State Head Injury Association)*

**Purpose**—There are six overlapping objectives or purposes in this 3-year study funded by the National Institute on Disability and Rehabilitation Research: 1) to re-analyze existing surveys in preparation for a

statewide survey of stress, coping, and functioning in families with a child traumatic brain-injury survivor; 2) to design and conduct a statewide survey; 3) to review evidence for efficacy of inter-



ventions which are susceptible to family-professional partnership involvement at the critical stages of the post injury restorative process; 4) to conduct a nominal group process involving selected families and professionals to refine interventions showing potential for family-professional partnership involvement; 5) subject to external funding, to implement and evaluate one or more interventions that rely on a significant family-professional partnership; and, 6) to disseminate findings and training materials resulting from objectives 1 to 5 above.

**Progress**—The New York State Head Injury Association (NYSHIA) has been locating a suitable family sample of at least 180. This sample represents families from low, medium, and high socioeconomic status and from three time periods following the traumatic brain injury. NYSHIA prepared for a nominal group process for ten representative families in October 1989. The purpose of the nominal group process was to help selected families to choose interventions subject to professional-family partnership.

A survey instrument based on the Double ABCX Model of Family Stress and Adaptation has been developed. They have pilot tested it on five selected families in Western New York. An inte-

grated research review of interventions, for the purpose of determining the efficacy of these interventions and their adaptability to family-professional partnership has been completed, primarily with other disability groups, including mental retardation, mental illness, and physical disabilities. Intervention protocols based on these reviews in preparation for the nominal group process have been developed.

**Preliminary Results/Future Plans**—Thus far, it appears that there are few interventions either in the head injury field or in other disability fields which have helped families cope with the burden of caring for a disabled child. During the second year of this study, the researchers will survey a large group of these families to discover their needs, problems, and coping strategies. They will also help families to plan and choose interventions based on the model of family-professional partnership. Based on the findings of the second year, an intervention will be tested for its efficacy during the third and final year of the study.

#### **Publications Resulting from This Research**

None reported.

### **[414] Development of an Outcome-Oriented Head Injury Database**

**Samuel L. Stover, MD**

University of Alabama at Birmingham, Birmingham, AL 35294

**Sponsor:** *Centers for Disease Control*

**Purpose**—From among the millions of head injuries that occur each year, thousands of individuals survive to face significant physical, cognitive, and emotional difficulties associated with recovery. Unlike physical problems, cognitive difficulties do not necessarily diminish with time. At present, it is unclear which head-injured persons with residual cognitive deficits are most likely to benefit from extensive professionally-directed care, as there is no consensus as to what the "average" severely head-injured person is able to do, given a specific time post onset. The objectives of this project are: 1) to develop a transportable rehabilitation outcome-oriented head injury database; 2) to document the

natural history and clinical course of this disorder; and, 3) to facilitate rigorous comparison of various management and rehabilitation strategies.

**Methodology**—A list of demographic, acute care, and follow-up variables to be included in the database have been developed. Variables will be defined and collection procedures detailed in an instructional syllabus. Computer programs are being written for data entry, quality control checks, error detection, and management reports.

**Preliminary Results**—Existing head injury protocol and data collection instruments from institutions

across the country have been collected and evaluated. A data collection syllabus has been developed and contains 100 variables on demographics, acute care, and follow-up care. Data collection instruments and guidelines have also been developed. Pilot data have been collected on 100 patients. Variables have been revised and/or deleted as needed. Revisions have been made based on this study. Computer software development has begun and revisions and refinements of the system will be made through February 1990.

**Future Plans**—Development of data entry, quality control, statistical analysis, and report generation programs for this database is continuing. We plan to field test the software at two to three other Centers during the next year.

**Publications Resulting from This Research**

None reported.

## [415] Stroke Clinical Center

**Bruce M. Coull**

Oregon Health Sciences University, Portland, OR 97201

**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—The major thrust of this project is to assess the community (the state of Oregon) profile of strokes. Our investigations emphasize therapies focused upon stroke patients in three broad areas of importance: 1) preventive therapy; 2) acute medical treatments; and, 3) rehabilitation intervention for higher cortical impairment.

Preventive therapies are designed to assess various risk and prognostic factors in stroke patients to develop better molecular handles on both acute therapy and prevention. Factors which may yield to better identification and therapy of risks are: mononuclear cell cholesterol ester hydrolase activity; glycosylated hemoglobin; cholesterol turnover in

atheromatous plaques; and, physicochemical bases for platelet behavior in stroke. Acute medical treatments focus initially upon the potentially beneficial assessment of prostacyclin infusion. In addition, staged, sequential evaluation of aminophylline/barbiturate and vasopressors will be continued in a prospective, randomized fashion. Rehabilitation intervention for higher cortical impairment deals with neuropsychological and language impairments with compensatory learning strategies.

**Publications Resulting from This Research**

None reported.

## [416] Functional Recovery After Focal Cortical Injury

**Ruthmary K. Deuel**

Washington University/Pediatrics, St. Louis, MO 63178

**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—Using recently described quantitative techniques, we documented severe metabolic brain dysfunction far distant from surgically-placed lesions in the association cortex of monkeys. Two (frontal and parietal) hemisensory neglect syndromes were documented using behavioral testing. Symptoms correlated in time with metabolic anatomically intact foci of glucose hypometabolism, not structural damage

per se. Further, neglect animals' behavioral data point to moment-to-moment neural activity changes related to conditions of stimulus presentation. A definitive explanation for neglect symptoms is thus offered for the first time.

**Methodology**—We propose to further test and expand our original findings using methods previously



validated in this laboratory, including: 1) 14C-2-deoxyglucose autoradiography (2DG) to determine quantitative local cerebral glucose utilization (LGU), as an indicator of regional neural activity; 2) operative unilateral lesions that reproducibly induce neglect and other symptoms; and, 3) quantitative behavioral measures of neglect symptoms and their recovery. We will add computer-assisted densitometry and image analysis to improve accuracy of the LGU measure and computer control of behavioral tests to allow a measurement of orienting efficiency. These methods will be used in experiments to: 1) vary neglect symptoms vis-a-vis distant metabolic dysfunction in frontal and parietal animals. For example, neglect animals infused with 2DG while performing symmetrical motor activity will be sacrificed and the distribution of label compared with the distribution in previously studied non-performing operated animals; and, 2) determine

if other operative lesions outside frontal and parietal association cortex are accompanied by distant metabolic effects and if there are behavioral changes that correlate with them. For example, we will make unilateral superior colliculus (SC) lesions, and sacrifice with 2DG acutely, and after spontaneous recovery in resting alert monkeys.

**Implications**—These primate model studies will advance understanding of the distant metabolic effects of focal cerebral damage, and will provide direct correlates for diagnosis and management of human stroke patients, in whom recovery is often impeded by neglect and other higher cortical function deficits.

#### **Publications Resulting from This Research**

None reported.

### **[417] Rehabilitative Software for Head Trauma**

**Sandra E. Hutchins**

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**Sponsor:** *National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—The goal of this project was to develop a software program that would help the head injured help themselves.

**Results**—The result is a new software program, "Rehabilitative Software for Young Adults with Head Injury." The three program disks address both academic (reading, writing, and math) and cognitive (memory, attention, and problem-solving) skills. Not only is the subject content appropriate for the adult learner, it is also presented within story lines that present situations which the typical brain injured young person is likely to experience. To

make the software more personal and concrete, a database is included with each program that allows incorporation of the patient's demographic, school, and work history into the story lines, along with the names of friends and relatives. The software is designed to enable the head trauma patient to learn independently, but extensive documentation is provided for therapists and teachers working with the patient. The software is available in both "home" and "clinic" versions.

#### **Publications Resulting from This Research**

None reported.

**[418] Studies of Spasticity in Brain-Injured Patients**

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**Richard D. Penn**

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*Sponsor: National Institute of Neurological Disorders and Stroke, National Institutes of Health*

**Purpose**—The goal of the proposed grant is to objectively test the effectiveness of intrathecal baclofen for spasticity. Patients with spasticity that significantly interferes with motor function or causes painful spasms will be screened with injections of intrathecal baclofen. If they respond, a programmable drug pump will be implanted to give the medicine chronically. The dose levels needed to control painful spasms, clonus, and rigidity will be determined. Voluntary control, if present, will be tested in the Motor Control Laboratory. Once the optimal dosage has been selected, the patient will receive the drug continuously. Quantitative studies of motor function, as well as activities of daily living, will be assessed at regular intervals. The

prospective study will provide information about the long-term efficacy, as well as the risks of the procedure.

A secondary goal will be to relate decreases in rigidity, hyperactive reflexes, and clonus to voluntary control. The basic question is whether a reduction in the signs of spasticity necessarily means that voluntary control will improve. If voluntary control does improve, what signs are most predictive, and can these measurements be used to select the patients who will respond best to treatment?

**Publications Resulting from This Research****None reported.**



## XIV. Geriatrics

*For additional information on topics related to this category see the following Progress Reports: [33], [124], [125], [126], [309], [314], [346], [347], [355], [391], [463], [466], [477], [494], [525].*

### [419] Interventions to Improve Dressing Behavior in Cognitively Impaired Veterans

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #E558-RA)*

**Purpose**—The purpose of this study is to measure the effectiveness of a set of patient specific interventions called Strategies for Promoting Independence in Dressing (SPID), for improving the dressing behavior of cognitively impaired elderly veterans. The findings are expected to provide information helpful in reducing the veteran's excess disability. Thus, it will help improve their self-esteem and consequently their quality of life.

This project is testing the hypothesis that there will be a difference in the assistance required by subjects in the performance of dressing before and after receiving the clinical intervention of SPID. The secondary objectives of this study are: 1) to explore the relationship between the type of assistance given during dressing and the aggressive behavior of the subject; and, 2) to clarify the relationship between specific cognitive deficits and the types of assistance needed in performing dressing.

**Methodology**—We are using a pretest-posttest design in which each subject will serve as his own control. The two major dependent variables being measured are: 1) the level of assistance that the subject requires during dressing (Beck Dressing Performance Scale); and, 2) the number of aggressive behaviors that occur during dressing (Ryden Aggression Scale).

The study is being conducted with cognitively impaired veterans on the nursing home care units, the geriatric rehabilitation unit, and the psychiatry units. Following admission to the study, approximately 15 subjects on two units will be videotaped during dressing twice a week for 1 week to desensi-

tize them to being videotaped. They then will be videotaped during dressing twice a week for 2 weeks. Two trained raters will view the videotapes to establish a baseline level of assistance required during dressing and the incidence of aggressive behaviors. The subjects will then receive the 6-week clinical intervention. The clinical intervention will consist of specific environmental, interactional, and cognitive strategies designed to increase independence in dressing. The intervention will be individualized to the specific disabilities of each subject and prescribed by a clinical nurse specialist. It will be implemented by LPNs and nursing assistants who will be given special training to apply SPID with the cognitively impaired veteran. During the clinical intervention period, the subjects will be videotaped twice a week. These videotapes will be reviewed by two trained raters to rate the patient-caregiver interaction using the Beck Dressing Performance Scale (BDPS) and the Ryden Aggression Scale (RAS). At the end of the 6-week treatment period, subjects will again be videotaped twice a week for 6 weeks post-treatment and at 3, 6, 9, and 12 weeks post-treatment for follow-up. These videotapes will be rated using the BDPS and the RAS. This process will then be repeated on approximately 30 patients on a second two units. Data analysis will involve repeated measures analysis of variance (ANOVA) and time-series analysis.

**Progress**—The training program and training materials have been developed for teaching the intervention to the nursing staff. Patients have been pre-screened for the study and consents have been

obtained from patients on the first unit. Delays in equipment procurement have delayed the start of data collection.

#### **Publications Resulting from This Research**

None reported.

### **[420] Electromyographic Incontinence Alert Device**

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*Sponsor: VA Rehabilitation Research and Development Service (Project #B376-DA)*

**Purpose**—The purpose of this project is to identify perianal electromyographic (EMG) changes that are associated with urinary incontinence in elderly men and to develop an electronic device that can continuously process the EMG signal and determine characteristic wave patterns preceding involuntary voiding to allow an alert signal to the patient of an impending incontinence episode.

**Methodology**—A 4-channel telemetric monitoring unit has been developed that continuously monitors perianal EMG, rectus abdominis EMG, intravesical pressure, and urinary incontinence. The output of each channel is digitized and recorded on magnetic tape. The analysis of the EMG changes are correlated with changes in abdominal pressure, intravesical pressure, and the actual occurrence of an incontinence episode.

**Progress**—The initial telemetric unit has been modified to include continuous measurement of intravesical pressure in order to determine the relationship of EMG changes to involuntary bladder contractions as well as the actual incontinence event. The EMG waveform preceding an involuntary detrusor contraction has shown a characteristic irregular pattern that precedes the sharp fall in amplitude that previously has been described before a bladder contraction. This irregular waveform is

now being analyzed for utilization by the EMG early warning device. Utilization of the irregular pattern will provide a longer interval between the patient alert and the subsequent involuntary bladder contraction than utilization of the fall in amplitude as was done in the original device.

**Results**—The incontinence episodes in elderly men have an irregular pattern of volume per episode and time interval between episodes. The irregular pattern suggests that the involuntary bladder contraction associated with urinary incontinence is independent of the accumulated volume of urine in the bladder. These data are consistent with differences in amplitude and duration of intravesical contractions during involuntary voiding. Simultaneous and continuous monitoring of intravesical pressure was added to the telemetric unit.

**Future Plans**—The prototype alert unit will be developed based on the irregular EMG patterns preceding the involuntary detrusor contractions. Clinical evaluation of units will be completed during the project as well as appropriate modifications of the design based on the performance of the units.

#### **Publications Resulting from This Research**

None reported.



## [421] Accelerometric Body Motion Detection in the Fall-Prone Elderly: A Pilot Study

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Sponsor: VA Rehabilitation Research and Development Service (Pilot Project #E972-PA)

**Purpose**—Recent advances in acceleration measurement and real-time data processing technology are being applied to analysis of upper body instability contributing to or accompanying falls in the elderly. In a preliminary study, acceleration sensors were placed on the head and waist of normal and fall-prone subjects during laboratory tests of postural stability and balance and during simulated negotiation of the hospital environment.

Acceleration data from each subject was analyzed to distinguish movement patterns common to all persons performing a balance test or other activity from those characteristic of poor postural control.

Two prototypes of a special purpose portable data acquisition package are being built; these incorporate internal microcomputers and memory with post-test connection to a stationary computer for analysis. The package measures 2 inches by 3 inches by 6 inches, weighs under 3 pounds, and is similar to a Holter cardiovascular monitor.

Ultimately, improved instrumentation should make it possible to: 1) record an individual's movements during an interval preceding a spontaneous fall regardless of location; 2) identify patterns of movement that accompany loss of balance before a fall actually occurs; and, 3) alert the individual of prefall behavior and, if necessary, signal a remote attendant that a fall has taken place.

**Methodology**—In a typical laboratory test, subjects wear a headband and belt, each with two 3-axis accelerometers. Four sensors are needed to distinguish rotational motions from translational (straight line) movement. Body movements are both conventionally videotaped and videophotographed using reflective targets at joints. Subjects perform tasks such as: standing with eyes open or closed on a firm or soft foam surface; climbing up and down steps; leaning at the waist; rising and sitting in a chair;

tandem (toe-to-heel) walking; turning sharply; stepping over 2-, 4- and 8-inch obstacles placed 3 feet apart; and bending forward at the waist to retrieve a pencil from the floor.

**Results**—Twenty-three young and old subjects were tested. A young athletic subject, standing quietly with eyes open, produced acceleration magnitudes at each of the four sensor sites typically no more than  $\pm 0.005$  g, with isolated 0.01 g peaks. One elderly subject had about the same 0.005 g baseline motion, but three times as many peaks of 0.01 g; with eyes closed, the baseline motion doubled at the head but not at the waist. This finding agrees with published balance studies and suggests a cause related to increased latency of reaction time. Another less stable elderly subject with eyes closed had episodes of acceleration up to 0.047 g corresponding to "wavering" stance.

Missteps during toe-to-heel (tandem) walking were clearly identifiable; one type of misstep produced vertical and anterior motion of the head apparently related to catching the toe on the floor: another caused more lateral acceleration or sway.

When elderly and young subjects climb up stairs, acceleration magnitude changes rapidly going up each step, but deceleration to rest on the step is more prolonged (about 1:3 ratio). In climbing down stairs, *no* peaks at the head of the young subject exceed 0.4 g, while *all* peaks of the elderly subject exceed 0.4 g and reach 1.05 g. Peaks at the young subject's head are smooth relative to the waist, but in the elderly subject, peaks are sharper. This finding is consistent with stiffening of shock absorbing soft tissues such as intervertebral discs and results in transmission of more foot impact up the vertebral column to the head.

**Future Plans**—A proposal has been submitted to continue the project, thus expanding the numbers

and etiologies included in the subject population, examining induced falls on the Neurocom "Equitest," and exploring accelerometric feedback in fall-avoidance and injury-prevention training.

**Publications Resulting from This Research**

None reported.

**[422] Psychiatric Rehabilitation in Nursing Homes**

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*Sponsor: VA Rehabilitation Research and Development Service (Project #E403-RA)*

**Purpose**—Nursing homes are now the largest single place of care for the mentally ill, yet nursing home staff have had little or no training in working with psychiatric patients. Existing studies show deterioration in behavior of mental patients after nursing home placement, when compared with similar patients randomly assigned to Veterans Affairs (VA) nursing care units, or continued psychiatric hospitalization. In the face of further financial constraints and an aging population of patients, it is likely that even more psychiatric patients will be sent to community nursing homes. Many of these patients have a potential for psychosocial and functional rehabilitation, and in others, behavioral deterioration could at least be forestalled. Training and consultation to staff in nursing homes offers the potential for improving psychiatric care. The objective of this research is to test the effects of training and a cost-effective method of consultation for psychiatric rehabilitation in nursing homes.

**Methodology**—Nine nursing homes were randomly assigned to either a training program designed to increase staff knowledge and attitudes about caring for the mentally ill, or to control conditions. Following the training, mental patients admitted to the homes have been studied regarding behavioral outcomes at 6 and 12 months, as well as whether treatment goals were attained. Half of the patients

were randomly assigned to have their treatment goals discussed with nursing home staff so the effects of individualized feedback to staff about patients could be evaluated. If this study shows that the training feedback improves staff knowledge and attitudes as well as psychiatric patient outcomes, then the method would be a cost-effective one for upgrading psychiatric services in nursing homes.

**Results**—The training of staff in nursing homes randomized to training was completed in December 1987. There were significant positive changes in attitudes, knowledge, and skills of staff in trained, compared with control, homes. Intake of patients into the nine nursing homes randomized to training, ongoing consultation, or control conditions was initiated in January 1988. To date, 219 patients have met criteria of a psychiatric diagnosis and been pretested on their behaviors and goals for treatment. A total of 97 have had 6-month evaluations completed, and 44 have had 12 months completed.

**Future Plans**—The plan is to continue patient intake, pretesting, and 6- and 12-month follow-up testings initiated at appropriate times.

**Publications Resulting from This Research**

None reported.



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**[423] Assessment of Age-Related Changes in Visual Spatial Organization**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #C426-RA)*

**Purpose**—This is a 3-year study of age-related changes in visual function and the judgment of egocentric distance, depth, and apparent size. In the study, visual performance is being assessed on approximately 200 normally-sighted individuals from two age groups (20 to 35 and 55 to 70 years of age). The participant's performance on a battery of clinical and psychophysical tests of vision (e.g., accommodative flexibility, contrast sensitivity, macular stereopsis, tonic vergence, and near and far acuity) is being compared with their judgments of distance, depth, and size in reduced- and enhanced-cue environments. These data will be used to determine relationships among basic visual function, age, and elements of spatial organization. Completion of the study will yield a baseline evaluation upon which comparisons with other groups (e.g., older, low-vision observers) may be made.

**Methodology**—All participants in this study are given clinical screenings to exclude the presence of age-related pathology such as glaucoma, cataracts, or macular degeneration. All participants have at least 20/20 near and far acuity corrected vision. Upon reporting to the laboratory, each participant is further screened for lateral and vertical phorias, contrast sensitivity, and visual field extent.

A computer-driven test of tonic vergence is administered by the Parameter Estimation by Sequential Testing (PEST) protocol. The observers are then presented non-familiar ("anomalous") target objects of different physical sizes and requested to make judgments of egocentric distance and size. In some conditions ("dynamic trials"), the observer walks a specific distance toward the object and makes the distance and size judgments.

A similar format is used with a familiar target object (an "Exit" sign). A novel test of the judgment of short depth intervals is provided through the repeated presentation of a simulated "staircase" in which the inter-step separation is randomly varied from 4 to 12 inches. A cross-modal response is elicited by having the observer move a step-like apparatus, by foot, until the separation is judged to be the same as the apparent inter-step separation viewed. Each observer makes judgments of the inter-step depth under both unrestricted and restricted (approximately 14 degree) viewing conditions.

**Progress**—Data collection incorporating the above methodology is ongoing. Other tests under continued development include an infrared retinoscope which provides real-time measures of accommodative flexibility and an applied test of near-macular stereopsis. These tests will be implemented for approximately one-half of the subject population.

**Results**—No summary statistics are currently available.

**Future Plans/Implications**—This study will establish normative data for future studies which will investigate the effects of age-related pathology upon visual distance, depth, and size perception. Additionally, this study supports other laboratory research concerning the human factors of safety and mobility in architectural environments.

**Publications Resulting from This Research**

None to date.



## [424] A Systematic Observation of Wandering Behaviors in Older People and Contributing Factors

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #E402-RA)

**Purpose**—The purpose of this study was to capture and describe the unique travel patterns of nursing home residents labeled “wanderers,” and to explore the relationships between the expression of these travel patterns and a variety of psychological and nonpsychological factors. The following research questions were addressed in this study: 1) What kinds of travel behaviors constitute wandering activity? 2) How do psychological factors such as dementia and depression affect wandering? 3) Do nonpsychological factors like demography, previous occupational demands, or physical impairments play a role in wandering? 4) Is medication an important contributing factor to wandering? and, 5) What are the risks associated with the expression of wandering travel behaviors?

**Methodology**—This study used an observational methodology based on video monitoring to capture the travel behaviors of nursing home residents, a portion of which had been identified by nursing staff to be wanderers. Travel behaviors were evaluated by two independent raters using a reliable coding scheme developed for this study. All participants were evaluated with respect to cognitive and emotional status, demography, and medication regimens. Participants were classified as efficient or inefficient travelers based on travel behavior and compared with respect to a variety of factors.

**Progress**—A total of 30 subjects have completed the study protocol at one site. The coding scheme was developed; interobserver reliability has been determined.

**Results**—In general, nursing home residents’ travel was efficient in that routes traveled were relatively direct from one location to another. However, a number of residents also engaged in travel behaviors that were inefficient, including repetitively lapping areas (circuiting) and/or random patterns of move-

ment (meandering). Participants were categorized into two groups composed of individuals whose travel was always efficient ( $n=10$ ) and those who exhibited either meandering or circuiting at least twice a week ( $n=8$ ). Comparisons between these groups revealed that differences were limited to cognitive factors. No differences were found with regard to demography, physical demands of previous occupations, physical disabilities affecting activities of daily living, or the prescription of psychotropic medication. Although both groups appeared cognitively impaired based on their total Mental Dementia Rating Scale (MDRS) scores, the inefficient travel group was much more profoundly impaired.

Impairment of recent memory ability was the most important factor that separated the two groups. Additionally, the study showed a significant but modest temporal association between exiting supervised areas and inefficient travel behaviors (circuiting or meandering). This finding suggests exhibiting these behaviors is not without some degree of risk for elopement. Finally, the emergence of these behaviors was interpreted to be symptomatic of the later stages of Alzheimer’s disease.

**Future Plans/Implications**—The plan is to replicate the study protocol with ten more subjects from the current study site. Following this, the study will move to another site and increase the sample to 80 participants. Results to date have shown that wandering activity can be objectively measured in a relatively simple manner using either an observational methodology as in this study, or, in the future, by developing the technology to electronically map travel patterns of elders.

### Publications Resulting from This Research

**A Systematic Observation of Wandering Behaviors and Psychologic Correlates.** Martino-Saltzman D, in *Proceedings of the Gerontological Society of America Annual Scientific Meeting*, 1989.



## [425] Spatial Orientation and Wayfinding in Elderly Persons

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #E428-RA)*

**Purpose**—Becoming lost or disoriented while attempting to move about familiar environments while engaged in everyday life activities is a major problem for many elderly persons. Anecdotal accounts of this problem are common. It is not unusual to hear of elderly persons, long-time residents of a neighborhood, who suddenly find themselves unable to find their way home when walking the dog, or who become afraid to leave their homes for fear of becoming lost.

A recent survey of 170 nursing homes revealed that such anecdotes characterize a significant proportion of the elderly population: approximately 25 to 50 percent of the residents were described as disoriented to their own building.

The component processes of wayfinding are poorly understood. This 3-year study is an attempt to provide a better understanding of the changes which occur with age in the component processes of wayfinding and to evaluate the impact of such changes in wayfinding on the daily functioning of older persons, especially following the person's relocation to an unfamiliar environment.

Individuals of three specific age groups will be compared in a residential setting. The comparison will include the efficiency of wayfinding and its components: 1) knowledge of the environment; 2) knowledge of one's location in relation to specific landmarks in the environment; and, 3) retrieval and usage of this information. Factors related to wayfinding competence in the elderly will also be studied, including: 1) frequency and range of travel; 2) wandering behavior; and, 3) mood.

**Methodology**—The proposed study will consist of two parts. Part 1 will be a comparison of 34 middle-aged, young-old, and old-old adults on measures of spatial ability in an unfamiliar building following a brief, controlled exposure to the building. Elderly adults selected for participation will be individuals recently admitted to a large retirement center. This situation, one objective of the overall

project, compares performance on this controlled task with spatial behavior in a more natural setting (i.e., the independent living center).

Part 2 will be a follow-up of the young-old and old-old adults after admission to the retirement center. It is designed to examine the relationship between wayfinding competence as measured in Part 1, and various measures of adjustment to the nursing home. These include: the subjects' spatial orientation and wayfinding competence in the nursing home and immediate environment; self-confidence in wayfinding; range of travel; wandering behavior; mood; and general level of functioning. Assessments will be conducted at 2 weeks, 2 months, and 6 months; thereafter, each 6-month interval will be assessed for a period of 2 years.

Elderly adults selected for participation will be individuals who have recently (within 2 weeks) moved to a large retirement center. Middle-aged adults will be selected among recently hired employees and/or volunteers of the Atlanta, GA, VA Medical Center. This selection ensures that the group is similar (gender and educational levels) to current residents of the retirement center.

**Progress**—All site plans and questionnaires were designed, retirement centers were contacted, and the protocol for contacting new residents at the time of admission was designed and initiated. Data are currently being collected on the retirement center population and on new VA employees and volunteers.

**Future Plans/Implications**—The results of this study will have implications for orienting older adults to new environments. There are hopes that depression and adjustment to new settings will be lessened because of the knowledge gained.

### **Publications Resulting from This Research**

None to date.



## [426] Motivational Devices for Promotion of Aerobic Exercise in the Elderly

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Center for Rehabilitation Medicine, Atlanta, GA 30309

**Sponsor:** *VA Rehabilitation Research and Development Service (Project #E425-RA)*

**Purpose**—The objective of this 2-year project was to evaluate the influence of exercise enhancement devices on the attitude and perception of exertion of young, middle-aged, elderly, and wheelchair-confined subjects. The use of different age groups is intended to ascertain if preference in environmental conditions during solitary exercise is age related. However, due to a limited time factor, the young age group was dropped.

**Methodology**—After completing an initial sub-maximal exercise test and psychological tests, 80 ambulatory subjects selected either a treadmill or a stationary bicycle for exercise. The wheelchair subjects were limited to a modified exercise roller. The same device was used in all three experimental exercise conditions.

The first exercise condition included the subject interacting with the device in a game-like protocol (a cartoon figure walking a dog) which reflects the physiological and motor reactions of the exercising subjects. This video game is designed to be fun, challenging, and to motivate the user to exercise in the target heart rate zone, thus keeping the user safely within the limit of their exercise prescription.

The second condition involved a noninteractive video display of exercise views in pleasant environments (environmental scenery as the camera is moved at a bicycling or running pace). The third

condition involved stationary exercise without the use of any motivational devices. The subject's heart rate was only seen by the technician; however, if the exercises were of an intensity above the subject's range, the program shut off and terminated that particular session.

**Progress**—To date, 12 subjects completed the protocol; 10 others are in the process of finishing. Experimental testing should be completed by April 1990.

**Results**—Preliminary results show that in the middle-aged group, 4 preferred the video game and 7 preferred the video tape. Only one in the elderly group finished and preferred the video game. Even though each subject had a definite preference for either the video game or tape, only 6 of these subjects exercised the longest under the preferred condition.

**Future Plans/Implications**—A follow-up phone survey will be conducted in Fall 1990 to see if the subjects are compliant with the exercise prescribed to them at the end of the sessions.

### **Publications Resulting from This Research**

None reported.

## [427] Predicting Wayfinding Ability from Laboratory-Based Spatial Tasks

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #F525-RA)*

**Purpose**—The primary goal of this study is to ascertain if measures of microspatial (tabletop tests) abilities are related to wayfinding abilities in

macrospatial (real world) environments. The ability to accurately identify physically disabled persons at risk for disorientation would facilitate intervention



in spatial orientation. If measures of "tabletop" or paper-and-pencil spatial abilities correlate moderately or well with large space wayfinding, then it may be possible to use microspatial tasks for screening and selection of military personnel for jobs requiring a high degree of spatial ability.

**Methodology**—To complete this research, subjects ranging in age from 18 to 35 years old will be given a battery of "tabletop" or paper-and-pencil spatial tests from the *Kit of Factor Referenced Cognitive Tests*. The tests tap various aspects of this complex behavioral domain (e.g., spatial visualization, memory for spatial information, spatial closure). Subjects will perform a set of tasks which involve viewing a 4- by 8-foot model town; they subsequently respond to questions which tap perspective verification and map verification. Finally, subjects will walk predetermined routes inside a building and outside in wooded areas and residential areas.

After these walks, subjects will perform tasks which tap general Euclidean orientation, feature recognition, temporo-spatial ordering of landmarks, map placement of landmarks, and route reversal. Differences in mobility in residential and rural settings is of interest because differences in the familiarity, quantity, and salience of environmental information between city and forest will likely affect wayfinding.

The primary purpose of the study is to deter-

mine the extent to which psychometric (i.e., paper-and-pencil) and experimental (i.e., model-based) spatial tasks predict performance on macrospatial abilities; adjunct data analysis will involve multiple regression analyses in which measures of macrospatial ability serve as the criteria variables, and psychometric and experimental tasks serve as predictors.

**Progress**—The investigators completed initial development of experimental protocol and are in the process of building a model town for use in the experimental tasks.

**Future Plans/Implications**—This study will identify which types of microspatial tasks show a valid and reliable relationship to selected macrospatial tasks in addition to the magnitude of those relationships. It may be possible, for example, to use the findings as a basis for establishing norms of spatial behavior across age and thus help in determining the differential effect of normal aging and sensory or cognitive decline as they affect spatial behavior. It may also be possible to extend this work to the identification of compensatory strategies which can be taught to civilians and military personnel in need of enhanced mobility or wayfinding skills.

#### **Publications Resulting from This Research**

None reported.

### **[428] Pupillary Function in Elderly Individuals with Impaired Night Driving Vision**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #E411-RA)

**Purpose**—Certain elderly individuals complain of vision difficulties when driving an automobile at night. If such individuals continue to drive at night, they expose themselves and others to the risk of injury or death due to accidents caused by impaired visual perception; if they stop driving, their independence and social fulfillment are adversely affected. The incidence of this complaint is unknown, as is the cause.

Pupil size and reactivity dynamically regulate

the amount of light entering the eye. Either insufficient or excessive light entry into the eye can degrade optical image formation. Impaired vision due to age-related ocular diseases such as cataracts and senile macular degeneration may be worsened by impaired regulation of light entry into the eye. This study was therefore designed to determine the incidence and characteristics of impaired night driving vision in a group of persons selected only for age (>55 years) and to determine the relationship



between this visual complaint, pupillary dysfunction, and age-related ocular diseases.

**Progress**—Eighteen subjects (7 male, 11 female; age range 53 to 81, mean age 72 years) were studied. A personal and family history of ocular and medical disease was obtained; visual acuity, intraocular pressure, slit lamp biomicroscopy, and fundus examination were performed on all subjects. Pupillometric measurement of the latency, velocity, and amplitude of constriction and dilation were performed using an infrared imaging system (ISCAN RK-416); output from this system was fed to an IBM PC-XT for waveform analysis. Of the study population, 7 complained of poor night-driving vision (2 males, 5 females; Group A, mean age 69 years), 11 did not (Group B, mean age 73 years). The age of symptom onset ranged from 48 to 81 years (mean age 62 years). Three subjects each had had a motor vehicle accident since age 60; one in Group A (accident at night), two in Group B (one accident at night, one at twilight). Of Group A, 86 percent noted visual difficulty with oncoming low beam headlights, 29 percent just after the headlights had passed, and 50 percent with low beams in the rear-view mirror. Difficulty with spatial confusion was reported while driving on dark roads in 43 percent of the subjects. On examination, more subjects in Group A had 20/30–20/40 visual acuity (OU) than in Group B (50 percent, Group A; 0 percent, Group B) and more subjects in Group B had 20/20 vision OU than in Group A (14 percent,

Group A; 55 percent, Group B). Intra-ocular pressure was similar between groups.

Examination of the lens and fundus could be performed on 6 or 7 in Group A, and all in Group B. Normal lens and retina were present in 0 percent of Group A, and 45 percent of Group B. Significant lens opacities (normal retina) were seen in 33 percent of Group A, and 9 percent of Group B; significant retinal abnormalities (macular degeneration, prosthetic lens) were seen in 17 percent of Group A, and 0 percent of Group B. Minor lens opacities with normal retina were seen in 17 percent of Group A, with 9 percent in Group B. There was no difference between groups in the percentage with either normal lens and insignificant retinal findings or minor abnormalities in both lens and retina. Analysis of pupillometric data between Groups A and B showed no statistical difference between mean latencies of constriction or dilation by Student's *t*-test for pooled data ( $p < 0.05$ ). Analysis of velocity and amplitude of constriction and dilation is currently in progress.

**Results**—Based on this preliminary data, subjectively impaired night driving vision commonly is associated with either lenticular opacities or macular degeneration, is related to headlight exposure, and is not due to abnormal latencies of constriction or dilation in the pupillary light reflex.

#### **Publications Resulting from This Research**

None reported.

### **[429] Why Don't All Impaired Elderly Fall?**

**Stephanie Studenski, MD, MPH**  
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**Sponsor:** VA Rehabilitation Research and Development Service (Project #E538-RA)

**Purpose**—The purpose of this study is to clarify the role of impaired mobility in falls among older persons. Impaired mobility is proposed to be a functional manifestation of losses across the components of postural control that can be described in a hierarchical framework. It is a necessary but not sufficient factor in chronic falls. Impairments in psychological, social, and environmental domains also contribute to falls risk.

**Methodology**—The protocol is designed in three phases. Phase One identifies subjects with impaired mobility. Phase Two, an in-home examination, identifies the degree of impaired mobility and detects contributions from the other three domains. Phase Three examines the neuromuscular manifestations of impaired mobility in a laboratory setting.

Eligible subjects are community dwelling male veterans aged 70 or older. Clinical measures include



a progressive mobility skills protocol with established hierarchical properties, a functional reach task, psychologic examinations of cognition and risk preference, instruments for emotional and instrumental social support, and a structured environmental assessment based on pathway theory. Laboratory instruments include a movable platform fitted with strain gauges, surface electromyography (EMG), and isokinetic dynamometry. Measures include visual functions, analysis of EMG in feedforward and feedback paradigms, peak torque, goniometry, and timed clinical endurance testing. The outcome, falls, is monitored with falls diaries and regular telephone contacts.

**Preliminary Results**—Each phase tests a specific hypothesis. In Phase One, we predict that falls risk is significantly higher in persons with impaired mobility compared to both persons independent in functional mobility and persons dependent in the lowest level of functional mobility. In Phase Two, we predict that, controlling for the degree of impaired mobility, falls risk increases with the number of impaired domains. In Phase Three, we predict that impaired mobility is significantly associated with prolonged response time and decreased strength at the ankle and hip.

#### **Publications Resulting from This Research**

None reported.

### **[430] Age-Related Changes in Sensory-Motor Performance**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #C390-RA)*

**Purpose**—The goal of this research is to understand the changes that occur in sensorimotor performance as healthy people grow older.

Our goals are: 1) identification of routine tests clinicians can use to identify and treat patients at risk for falling; and, 2) development of therapeutic regimes to prevent, treat, or compensate for deficits which place elderly people at risk for falls.

**Methodology**—We are evaluating healthy and neurologically-impaired individuals up to 85 years of age, with objective measures of myotatic reflexes, joint compliance, muscle strength, simple ankle joint voluntary movements, somatosensory evoked potentials (SSEP), standing balance, and gait. Correlations among these measures are made for each subject, and for the age- and sex-matched groups. Parameters of sensorimotor performance from healthy aging subjects will be used as a “template” against which to compare elderly patients with a history of falling or neurologic disease.

**Progress**—We have collected measures from normal volunteers (ages 18 to 40 years), aging subjects (45 to 85 years), and neurologically-impaired children

and adults. From these data, we are formulating our hypotheses.

**Results**—Despite the fact that our healthy aging volunteers are physically active, most have deficits in at least one measure of the neurologic exam, i.e., myotatic reflex, SSEP, joint stiffness or voluntary reaction times at the ankle, postural steadiness, or kinematic measures of gait. We are defining a spectrum of changes in function and electrophysiologic and biomechanical measures which occur as part of the aging process in healthy individuals.

Our active “healthy aging” subjects have fewer sensory-motor deficits than previously described for elderly subjects. Some of our measurements will be useful tools to discriminate healthy aging from neurologically-impaired individuals. Other tests indicate significant differences in all older subjects, and may be less useful to identify neurologic disease.

For several tests *averaged* data for healthy aging subjects are *not* significantly different from normal young adults. However, *individual measurement differences* exist between young adults and the elderly; individual performance measures are impor-



tant to differentiate the "successfully" aging person from the elderly person at risk for falls.

We have evaluated 56 patients with cervical spondylotic myelopathy (CSM). Some patients with cervical spinal cord impairment have stretch reflex abnormalities of the upper and lower extremities when neck position is altered. While CSM is a relatively common disease of the elderly, SSEPs, myotatic reflexes, and gait appear to differentiate aging subjects with debilitating disease. Whether these tests are useful predictors of deterioration requires further study.

Our research demonstrates that diversity of changes may occur in active, aging persons who do not have neurological or orthopedic diseases. Older persons who feel unsteady may have a number of sensory, motor, or neurological deficits which put them at risk for falling. We suggest that the aging process and risk factors for unsteadiness are multifaceted problems.

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### **[431] A Needs Assessment for Low Vision Elderly**

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**Sponsor:** *Illinois Society for the Prevention of Blindness*

**Purpose**—The purpose of the project is to administer a Low Vision Needs Assessment Questionnaire to a representative sample of 140 elderly patients age 60 years and older. The Low Vision Needs Assessment Questionnaire will measure: 1) the patient's perception of his/her ability to perform activities of daily living with large visual component; and, 2) the importance to the patient of obtaining low vision devices/training to enhance remaining vision to independently perform the desired activities, thus

improving quality of life. In addition, an assessment of the effects of social support, general health status, visual status, and training on the needs of elderly patients for low vision devices will be made.

**Progress**—Data collection on this project has begun.

#### **Publications Resulting from This Research**

None reported.



## [432] Attitudes Of and Toward Older Persons With a Disability: Their Measurement and Their Role in Rehabilitation

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Sponsor: National Institute on Disability and Rehabilitation Research

**Purpose**—Supportive attitudes and accurate knowledge of the rehabilitation of older adults with disabilities can go a long way in furthering successful health care. Conversely, negative attitudes and lack of knowledge regarding rehabilitation care of geriatric patients can be detrimental to patient rehabilitation outcomes. The patient's family and physician play a large part in determining the level of the older person's adjustment, level of functioning, health status, and life satisfaction. Thus the attitudes of these three key parties can be crucial and act as either facilitators or inhibitors of the rehabilitation process. For example, attitudes may influence patient motivation, support and assistance given by the family, and patient treatment by the physician. To date, no instruments exist that specifically measure attitudes toward older adults with disabilities.

This study is a 5-year project to: 1) develop psychometrically-sound scales that measure attitudes of and toward older persons with a disability; and, 2) investigate geriatric rehabilitation outcomes in relation to attitude patterns among the family, the doctor, and the patient. These findings will highlight which attitudes interfere with which rehabilitation outcomes, and disseminate information on how to reduce these barriers.

**Progress**—This project was started in April 1988. Currently, a draft form of the *Attitudes Toward Older Persons with a Disability Scale* has been developed and contains attitude items in the areas of psychological, social, and physical functioning of disabled older adults, policy and societal issues, personal contacts and feelings toward the disabled elderly, and myths regarding disability in old age.

The scale has 114 items and has been distributed to 285 men and women ranging in age from 18 to 75. Currently analysis of the items is underway to select the best 50 questions for the final scale version based on item variability, and the social desirability properties of the items.

Once the final version of the scale is complete, reliability and validity studies will be started. Test-retest and split-half reliability statistics will be done and standardization norms will be acquired from a national sample. Validation studies will be performed on four indices of attitudes, i.e., life satisfaction, satisfaction with social activities, daily living activities, and professional nominations of both older disabled persons with positive attitudes, and families (with a disabled member) with positive attitudes.

Originally, the project intended to develop a second scale to measure disabled adults' self-attitudes toward their disability and rehabilitation potential. However, adaptation of the *Acceptance of Disability Scale* by D. C. Linkowski seems more appropriate. A validity study is underway to determine whether this scale successfully measures the attitude issues of older adults with disabilities, as some attitudes may differ by age.

After the measures are completed, the role of family, patient, and physician attitudes will be investigated on a number of rehabilitation outcomes, including social participation, life satisfaction, living arrangements, health status, patient and family mood, and family interaction.

### Publications Resulting from This Research

None reported.

### **[433] Late-Life Effects of Early-Life Disability: Physical, Psychological and Socioeconomic Characteristics Comparisons with Age-Matched Controls**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Increased attention has recently been placed on late-life problems affecting people with an early-life onset of disability. Most persons with disability are now living to late life, but many are experiencing the onset of new medical and functional problems. Two of the largest such groups are people with post-polio and spinal cord injury (SCI). Post-polio individuals are experiencing primarily fatigue, weakness, pain, and loss of strength. The SCI population is experiencing multiple medical problems which include osteoporosis, renal disease, hypertension, respiratory and cardiovascular problems, and generalized amyloidosis. To date, no studies have been conducted which compare disabled persons to appropriate age-matched control subjects, and relatively little attention has been focused on the long-term psychosocial consequences of an early-life disability.

The objectives of this study fall into two separate areas. First, we will focus on a variety of medical, psychological, and social variables to determine if there are differences between age-matched groups of older persons with an early-life onset disability, with a late-life onset disability, or those that are not disabled. In this way we can determine to what extent the changes reported are due to aging

alone or due to the length of time a person is disabled. Secondly, we will look more closely at the aging person with an early-life onset disability: 1) to determine if there are gender differences found in health and functional changes associated with aging; 2) to determine the kinds of services these individuals need in order to continue their independence in the community; and, 3) to gather additional information to test a compensation hypothesis as a major factor in late-life sequelae to early-life onset disability.

**Progress**—This is a 5-year study initiated in April 1988. Data collection has begun with both the post-polio and the SCI groups. Information is being collected by a team consisting of a physician, psychologist, and physical therapist, and involves self-report data, in-depth interviews, and medical and functional assessments. Concurrently we are compiling a subject pool of non-disabled older persons, and persons with a late-life disability onset. We anticipate data collection with the second and third groups to begin in the Spring of 1990.

#### **Publications Resulting from This Research**

None reported.

### **[434] Effects of Age and Visual Loss on Independent Outdoor Mobility**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—This study is concerned with the effects of advancing age and vision loss on independent mobility outside one's house and yard. There has been virtually no study which documents the degree to which personal factors (e.g., degree and duration of visual loss, health problems, amount of mobility training) and environmental factors (presence of

sidewalks, availability of public transportation) affect independence in travel. Such study should prove useful in assisting service providers in targeting individuals for mobility training and in determining what types of training will result in the greatest degree of independence for blind and visually impaired older persons.



**Methodology**—Community movement patterns and degree of satisfaction with independent mobility were studied in three populations. In-depth interviews were conducted in the homes of younger and older blind and visually-impaired persons, and with older persons with normal aging sight. Interviews included self-report of frequency and type of independent travel, along with measures of physical, mental, and social status. All participants lived with someone at least four nights per week, and none of the subjects lived alone.

**Progress**—A total of 87 individuals were interviewed during the course of this study. Thirty-four persons were in the older blind group. They ranged in age from 62 to 83 years. Half of the older blind participants had some measurable acuity and half had light perception or less. All were living in a single family dwelling in the community and lived with at least one other person. None of the participants had significant physical limitations other than vision loss which limited their mobility, as indicated by self-report. All were legally blind. Twenty-eight persons constituted the young blind group in this study. They ranged in age from 22 to 59 years. As with the older group, half had measurable acuity but were legally blind, and half had no measurable acuity. The young participants met the same criteria cited for older blind persons regarding physical health and living situation. The 25 older sighted individuals also met these criteria, and had corrected acuity of 20/60 or better.

**Results**—Older individuals with normal aging sight and younger individuals with visual impairment or blindness reported about 1.5 destinations independently per week, while older persons with visual

impairment average about 0.5 destinations per week. Only 6 of the 35 older blind individuals reported any independent travel at all outside their house and yard. The presence of sidewalks appeared to be a significant contributor to independent travel among older individuals with vision loss.

Mobility training or duration of loss did not affect frequency of travel. Older blind individuals report significantly less satisfaction with their mobility than either of the other two groups.

**Future Plans/Implications**—The results of this study have implications for training of older visually impaired individuals in mobility and for family support of caregivers of older visually impaired persons. The results indicate that, in light of the dependence of blind older persons on the individuals they live with, it is important to work with these significant others when providing services for visually impaired and blind older persons. Proper training in use of sighted guide technique, for example, appears to be an important service that the orientation and mobility instructor should provide. In addition, when cane travel training is deemed appropriate, it seems likely that blind and visually impaired older persons would benefit most from training provided in one's own community, as generalization across environment of acquired skills may not occur.

Part II of this study, which is now underway, involves behavioral observation of older and younger blind and visually impaired persons in actual travel situations.

#### **Publications Resulting from This Research**

None reported.

### **[435] Aging with a Disability: The Late Effects of Polio**

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**Sponsor:** *National Institute on Aging, National Institutes of Health*

**Progress**—Three decades after the American polio epidemics of the 1940s and 1950s, a health crisis developed among approximately one-third of the estimated 600,000 survivors who range in age from

35 to 85 (National Center for Health Statistics 1987 Health Interview Survey). New polio-linked complications include weakness, severe fatigue, muscle and joint pain, respiratory and swallowing difficulties—



all of which result in an individual's reduced capacity to function in day-to-day life. Treatment recommendations include the use of additional assistive devices (braces, canes, and/or wheelchairs on a full or part-time basis), energy conservation techniques, and activity pacing. The purpose of the postdoctoral research project is to investigate the social and culture factors which contribute to an individual's ability to adapt and cope with the unexpected new disabilities acquired as a result of the late effects of polio during their middle and later years of life.

**Methodology**—Fifty subjects were initially interviewed during their 2-day evaluation at National Rehabilitation Hospital's Post-Polio Clinic. Data is being collected on the rate of compliance with treatment recommendations using structured telephone interviews at 6-month intervals and rehabilitation outcomes will be measured and analyzed. Fifteen extended life history interviews are being conducted with subjects in their homes and data will be analyzed to provide a broad portrait of the social strategies used by a subgroup of polio survivors to adapt to both the initial and later phases of polio.

**Preliminary Results**—Following the acute viral phase, polio survivors were challenged to recover physically and to achieve socially and economically, and many did. However, the strategy to "push beyond limits" which worked so well during the

rehabilitation phase and for competing successfully in American society is not helpful for coping with the late effects of polio. The new message—to learn how to identify physical limits and not push forward—constitutes a major shift in world view and personal identity. Thus, the sequence and timing of interventions recommended in the clinic setting is crucial for successful compliance.

Preliminary analysis finds that there are two subgroups of the clinic-based post-polio population: 1) persons for whom the late effects of polio are experienced as a "first disability;" and, 2) persons for whom the late effects represent a "second disability." Prior to their new limitations, the "first disability" subgroup did not perceive themselves as disabled, regardless of the extent of involvement and/or the presence of deformities. The "second disability" subgroup did identify themselves as being disabled prior to their new limitations, and currently regard themselves as being twice afflicted.

Disabilities once considered static, like spinal cord injury or polio, are now found to be chronic, with medical as well as psychosocial consequences. Post-polio clinics will serve as models for the effective delivery of rehabilitative services that help patients prevent further loss of function and learn how to manage their secondary disabilities.

#### **Publications Resulting from This Research**

None reported.

### **[436] Lipid-Clearing Agents to Prevent Steroid-Induced Osteoporosis**

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**Sponsor:** *None listed*

**Purpose**—Corticosteroids are an effective anti-inflammatory medication. Common adverse reactions to systemic steroid therapy are the development of osteoporosis and avascular necrosis of femoral head, hyperlipidemia, and abnormal liver function. The purpose is to investigate the efficacy of lipid-clearing agents in the prevention of osteoporosis of the femoral head from a prolonged steroid treatment.

**Methodology/Progress**—An animal study which involved the concomitant treatment with lipid-clearing drug and steroid was conducted. Lovastatin and bezafibrate, both lipid-clearing agents, were investigated for their effectiveness in preserving bone mass of the femoral head and improving cholesterol and triglyceride levels. Thirty-five adult New Zealand white rabbits, averaging 4 kg in weight, were used. Three rabbits receiving no medication were used as



the control. All of the others received weekly intramuscular (IM) doses of 6 mg methylprednisolone acetate. The steroid-treated animals were divided into three groups. Group I (steroid-only) of 10 animals received only the steroid treatment. Group II (lovastatin-plus-steroid) of 12 animals, and Group III (bezafibrate-plus-steroid) of 10 animals received daily oral doses of 20 mg lovastatin and 40 mg bezafibrate, respectively, in addition to the steroids. Serum cholesterol and triglycerides were measured biweekly.

Each of the treated groups was further divided into two subgroups which were sacrificed before and after 12 weeks for long- and short-term evaluation. The femoral heads and livers were collected, decalcified, and stained with hematoxylin and eosin for histological studies. The percentage of trabecular bone in the femoral head area which was measured using computer-aided histomorphometry had been compared for these four groups.

**Results**—After 12 weeks, the trabecular bone content of the steroid-only group was significantly lower than those of the three groups ( $p < 0.01$ ). There was no difference between the control, lovastatin-plus-steroid and bezafibrate-plus-steroid groups during the entire experimental period ( $p < 0.05$ ). The results also showed no difference in bone content between the right and left femoral heads in each of the four groups ( $p < 0.05$ ).

In the liver study, all of the steroid-treated groups showed different degrees of fatty metamorphosis with focal necrosis. However, there was no substantial difference between the steroid-only and lipid-clearing agent groups. Serum cholesterol levels significantly increased in the steroid-only rabbits and the elevated cholesterol moderately improved with the use of lipid-clearing agents.

This study demonstrates that prolonged steroid treatment has led to a significant bone loss in the femoral head. However, the concomitant use of lipid-clearing agent (lovastatin or bezafibrate) and steroids has the potential to retard the process of osteoporosis and preserve bone mass. The lipid-clearing agents seem to have no apparent effect on the liver.

**Future Plans**—Work will continue in the study of the effects of lipid-clearing agents on humeri, lumbar vertebrae, and iliac crests. A clinical study will be conducted on human subjects with rheumatoid arthritis, lupus erythematosus, vasculitis, and bronchial asthma.

#### **Publications Resulting from This Research**

**Preventing Steroid-Induced Osteoporosis in the Femoral Head Using Lipid Clearing Agents.** Wang GJ, Chung KC, Shen WJ, Stamp WG, *Transactions of the 35th Annual Meeting, Orthopaedic Research Society*, Las Vegas, NV, 14:457, 1989.

### **[437] Use of Technology to Promote Rehabilitation of Older Persons: Reducing Barriers to Independence**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Disabilities often make it difficult for the older person to function maximally at home; such persons are also at increased risk of injury through accidents. The effective incorporation and use of environmental features are central to the safety and rehabilitation of the older person, i.e., to maintain independence, prevent further disability, reduce family worry, and prevent institutionalization. Although technology has been widely used to solve problems of rehabilitation, this has not been partic-

ularly true in the field of geriatric rehabilitation.

This project's ultimate goal is to develop a sub-center on technology within the Rehabilitation Research and Training Center on Aging. Focusing on safety problems in the older disabled persons' homes, a set of critical problems will be identified.

**Methodology**—Existing commercial products designed to solve such problems will be tested in the home and/or laboratory setting and modifications



and developments of products will be conducted to fill identified problem-technology gaps. These phases of the project will utilize data from groups of professionals working with older disabled persons, as well as older disabled persons themselves.

Dissemination activities will be an important component in later phases of the project. The dissemination activities will include production of a home safety resource notebook, preparation of articles for publication, a central call-in telephone resource service, the development of product utilization workshops, and the presentation of information at conferences concerned with geriatrics, rehabilitation, or human factors.

**Progress**—This 5-year project is now midway in year two. A comprehensive literature base was compiled. Based on a review of this literature as well as the National Electronic Injury Surveillance System (NEISS) data, it was decided to focus the project on problems of burns/scalds, medication intake errors, and falls. Thus far we have been concerned with one of the major objectives of the project—the identification of critical in-home safety problems for disabled elderly. This objective is being studied using a sample of 30 health care professionals whose primary responsibilities include in-home assessments with older persons. These experts were given a survey and asked to nominate safety problems based on the project model which organizes home safety problems by *accident category* (falls, burns, medications), *selected activities* (e.g., walking, bathing, cooking), and *problem source* (environmental, functional, psychological).

**Results**—To date, preliminary analyses have been performed on these data. In general, there were few unexpected home safety problems offered by the experts. For example, when asked about falls related to walking, the most-cited environmental problems (in descending order) were unsafe floor surfaces, clutter in the environment, and poor lighting. The most-cited functional problems were impaired vision, poor balance, and decreased lower extremity strength. The four most-cited psychological problems were depression, poor safety judgment, fear of falling, and memory impairment. It appears that in-home assessors are confirming what other sources (e.g., NEISS data, existing literature) say are the most critical in-home safety problems for the elderly.

**Future Plans/Implications**—We will be selecting and evaluating products which are supposed to provide technological solutions to the safety problems identified by our in-home assessors. The parameters to be addressed in this evaluation are set forth in the project model and include the efficacy of the product in solving the environmental, functional, and/or psychological problems related to each accident category. Additional parameters include user acceptance and other issues of user friendliness. Based on this evaluation criterion, a numerical “product evaluation score” will be obtained. This score is intended to provide a method by which other professionals and lay persons can easily understand our evaluation of each product.

#### **Publications Resulting from This Research**

None reported.

### **[438] Managing Lower Urinary Tract Dysfunctions in Aging Women**

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**Sponsor:** *National Center for Nursing Research, National Institutes of Health*

**Purpose**—The overall goal of this project is to manage lower urinary tract dysfunctions in aging women. The effect of clinical interventions (exercise and biofeedback) on lower urinary tract dysfunctions in aging women are currently being studied. One objective is to test three types of intravaginal

devices for the purpose of circumvaginal musculature (CVM) evaluation in non-parturient and postpartum women using: 1) a balloon device with a plug and one-eighth-inch connector; 2) a balloon device filled with sterile water to be used for endurance training; and, 3) a balloon device filled



with high viscosity silicone for strength training. The devices are connected to a strain gauge and strip chart recorder. During contractions of the CVM, the dynamic characteristics of the muscles assessed are: 1) rate of pressure change; 2) maximum pressure sustained; 3) length of time pressure sustained; and, 4) rate of return to baseline.

**Methodology**—Three home training methods are used to determine the effect of exercise on the dynamic characteristics of the CVM in 150 women. Prior to initiating circumvaginal muscular exercise, a flexible intravaginal device is made from an alginate (Healthco, Dental Division, Boston, MA) mixture for each subject. Impressions are made of the vagina during contraction and relaxation of the CVM muscles. The impression is invested later in a dental stone split mold. After the stone is set, the alginate impression is removed and discarded and a permanent model is made of silicone rubber. The custom-made vagina-shaped balloon is fitted with an interchangeable device, depending upon which of the three home training methods was used.

**Progress**—The alginate impressions captured the rugae and muscle ridges which were reflected in the

silicone rubber models. Twenty women with symptoms of stress urinary incontinence were studied.

**Preliminary Results**—The outgrowth of this study resulted in the development of a pressure-sensitive posterior balloon device which provided an accurate and highly sensitive mechanism for controlling abdominal pressure in women with lower urinary tract dysfunctions. It also revealed that CVM variables were stable over 4 weeks without exercise initiation, while improvement occurred after exercise. These studies suggest caution in using urodynamic tests as outcome measures.

**Future Plans/Implications**—Long-range plans are to find clinical teaching interventions that can be implemented by women in the privacy of the home. To this end, research is being conducted to enhance the individual's control over continence mechanisms, thereby forestalling or preventing incontinence which can require expensive and invasive treatment.

#### **Publications Resulting from This Research**

None reported.

### **[439] Use of Environmental Control Devices by Nursing Home Patients**

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**Sponsor:** *National Institutes of Health, Biomedical Research Support Grant Program*

**Purpose**—Applications of electronic technology have provided people with disabilities with the potential for increased control over their environment. While electronic devices are widely available, many individuals who could benefit from them, have not. Many older persons have limitations in mobility, coordination, and joint movement as a result of chronic disease such as arthritis. Many of these individuals live in nursing homes, and while cognitively alert, are not able to control even simple appliances, such as light switches and radios. Electronic devices are available that can help them regain control over some areas of their environment. It is the purpose of this study to design for, and

experimentally test, the use of environmental control devices for those individuals with mobility and/or fine motor coordination limitations who are living in a nursing home. The study is measuring the usage of appliances and lights, and the locus of control of persons who will be given environmental control devices against a control group.

**Methodology**—Twenty alert, elderly, nursing home patients with mobility and/or fine motor impairments were randomly assigned to two groups. One group received hand-held remote control devices, an appliance module, and a wall switch module. Patients in both groups were given radios. Patients in



the experimental group were trained in the use of the device, and some modifications were made in the remote control, such as enlarging the button size by attaching a large washer to the button. All patients were tested, before the introduction of the devices, with Rotter's I-E Scale, Rosenberg's Self-Esteem Scale, and the McCarron Assessment of Neuromuscular Development. A Device/Appliance Utilization sheet was completed for each patient once a week.

**Progress**—Patients in the experimental group have been using the environmental control devices. Patients in both groups were fully tested at 6 months, and will be tested again at 12 months.

**Results**—Comparison of usage of radios and lights shows significantly greater usage by the experimental group.

#### **Publications Resulting from This Research**

None reported.

### **[440] Consequences of Discussing Do Not Resuscitate (DNR) Decisions with Elderly Patients: A Test of Physician Assumptions and Patient Reactions**

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**Sponsor:** *None listed*

**Purpose**—A significant number of elderly hospitalized patients have strong feelings for or against nonresuscitation following a cardiopulmonary arrest. However, many physicians are reluctant to discuss the pros and cons of such a decision with their patients because they fear it would unduly upset them and may cause the patient anxiety or depression. This reluctance by physicians can seriously interfere with a patient's right to participate in crucial medical decisions that involve them. This study intends to empirically test these assumptions of negative patient reactions and investigate positive outcomes when involving patients in discussion and decisions regarding their care following a cardiac arrest. Prior to the study, a survey of local physicians will be done to more systematically determine the kinds of reactions physicians anticipate patients would have toward a DNR/CPR discussion.

**Progress**—The study underway includes 100 medically stable geriatric rehabilitation inpatients. A randomized control group design with repeated measures is being used. Patients randomly assigned to the experimental group will receive a DNR/CPR discussion from their physician, while those assigned to the control group will receive a discussion on diet. Following the discussion, each patient will then make a decision regarding the care they prefer, a decision on choosing DNR or CPR in the experi-

mental group, and a decision on diet preferences in the control group. Data are being collected on patient reactions of depression, anxiety, death anxiety, and feelings of hopelessness. Positive patient reactions also hypothesized and measured are patient feelings of self-control over their medical care, and increased patient satisfaction with doctors and hospital care.

Currently, data have been collected on 33 patients. In addition to the experiment, a survey of 88 physicians was done to document which negative patient reactions physicians assume would most likely occur.

**Results**—Results of the physician survey were presented at the May 1989 American Geriatrics Society Conference in Boston. Briefly, 50 percent of the surveyed physicians assumed that a DNR/CPR discussion could lead to depression, general anxiety, and death anxiety for the patient. None believed suicidal tendencies would develop, and only 25 percent reported that the discussion could threaten the physician-patient relationship.

An interesting finding of the physician survey was that only 50 percent stated they would routinely initiate a CPR/DNR discussion with their patients, while 100 percent of the patients seen in the on-going study said they would want their physician to initiate such a discussion. This discrepancy points



to the very different views of physician and patient regarding the need for this discussion, and suggests the importance of notifying the medical community of the patients' perspective and wishes in this area.

#### **Publications Resulting from This Research**

None reported.

### **[441] Stress Management Training for Caregivers**

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**Lee Willis, PhD; Judith M. Mitchell, PhD**

Rehabilitation Research and Training Center on Aging, Rancho Los Amigos Medical Center,  
University of Southern California, Downey, CA 90242

**Sponsor:** *Southern California Alzheimer's Disease Diagnostic and Treatment Center at Rancho Los Amigos*

**Purpose**—This program is studying the stress-related issues experienced by caregivers of Alzheimer's patients. Prior studies have documented that intense levels of stress can be a common problem among family members caring for adults with brain impairments, including those with dementia. Consequently, caregiver stress can have problematic effects in a variety of ways and situations. It may lead to decreased motivation and competencies of the caregiver, it may produce frustration, anxiety or guilt feelings for the caregiver, and it can even be a source of stress for the brain-impaired adult. Long-term and cumulative stress experiences can put the caregiver at higher risk for infectious disease or stress-related illness such as cardiovascular disease and hypertension. Ill health can in turn impact the caregiving function.

The purpose of this project is to examine the effect of stress-coping skills training upon experienced stress and coping effectiveness for primary caregivers of adults with a diagnosis of Alzheimer's disease. If the caregiver's level of perceived stress can be reduced, and the coping effectiveness increased with this kind of intervention, then the rehabilitation goals of the family member can be

furthered, and the caregiver may be at less risk for decreased health.

**Methodology**—This study has just begun. A 6-week stress management training program will be held for caregivers of Alzheimer's patients identified by the Alzheimer's Program at Rancho Los Amigos Medical Center. Information will be collected on types of stresses and stress levels, coping strategies identified and used, and other variables associated with successful coping, such as personality traits and family supports. Results will be compared to those of a waiting-list control group measured over the same time period. Treatment effectiveness will be determined by comparison of the stress-related variables between the treatment and control group.

**Future Plans**—In future studies we hope to include physiological measures of stress, and examine their relation to reported stress levels and stress reduction achieved from the stress management training program.

#### **Publications Resulting from This Research**

None reported.

# XV. Sensory Aids

*For additional information on topics related to this category see the following Progress Reports: [213], [423].*

## A. Blindness and Low Vision

### 1. General

#### [442] Development of the Family Training Program Curriculum in Low Vision

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**Gale R. Watson; William R. De l'Aune; Steve Ehrnst; Jim Blair**

Rehabilitation Research and Development Center, Atlanta VA Medical Center, Decatur, GA 30033

*Sponsor: VA Rehabilitation Research and Development Service (Project #C512-RA)*

**Purpose**—This project was designed to study the low-vision component of the family training program at the Blind Rehabilitation Centers. These centers include the project site, VAMC Research and Development Center in Decatur, GA and two other VAMCs: Southeastern Blind Rehabilitation Center in Birmingham, AL and Eastern Blind Rehabilitation Center in West Haven, CT.

The objectives of the project are: 1) to develop and refine competencies in low-vision rehabilitation for family members of veterans who receive low-vision services; 2) to develop and assess the quality of teaching materials and methods to ensure family members acquire desired knowledge and skills; and, 3) to develop an evaluation methodology which will allow staff of the low-vision service to assess the effectiveness of the family training program in low vision.

**Methodology**—*Objective 1:* The curriculum will be written by the staff at the project site and at the two blind rehabilitation centers. Evaluation will be by the project advisory committee; members include supervisors and social workers of low-vision programs in both blind centers, a veteran who is visually impaired, a family member who attended the family training program, and two curriculum

specialists. After specific observable and measurable competencies are written, the advisory committee will be asked to rate the importance and achievability of each competency. Competencies will be revised and modified, and the finalized curriculum for the family training program in low vision will be disseminated to the staff of the Blind Rehabilitation Centers.

*Objective 2:* The project staff will develop a library of existing materials which are presently used in the low vision family training program. They will add to this library by completing a search for materials not presently utilized, but available. In addition, the staff will develop a complete bibliography of these materials which will include information for professionals such as the readability level of the material, page count, cost, whether the material is available in braille, large print, or cassette, and where it may be ordered, etc. The staff will develop new teaching tools which will allow staff to better teach family members specific competencies for which no materials presently exist.

*Objective 3:* An evaluation methodology will be developed which will allow the low vision service staff to objectively assess the effectiveness of the family training program. The methodology utilized will be one which will not "test" the family



member, but will allow the family member and low-vision staff to work together to assess the program and ensure that all information is provided and understandable.

**Progress—Objective 1:** The curriculum has been written, critiqued, revised, and disseminated to participating blind centers.

**Objective 2:** A library of materials is being developed. To date, over 100 references on all topics related to low vision, from specific eye pathology to use and care of low-vision aids, and psychosocial concerns are included. A videotape on making environmental modifications in the home is being developed.

**Objective 3:** An evaluation instrument for the family training program in low vision has been written. A questionnaire has been designed to be sent to the family member prior to entering the family training program, and will be brought to the family training program. The family member will complete the answers to questions daily and will

date answers so that project staff can ascertain when information was received. A follow-up questionnaire can be sent after program completion.

**Results—**The family training curriculum is completed and disseminated to the Blind Centers. A library of curriculum materials for training family members has been developed. The questionnaire was developed and sent to project advisory committee members for review and input.

**Future Plans/Implications—**Future plans include the evaluation of the low vision family training curriculum using the questionnaire to study the effectiveness of the curriculum. Also, the staff have discussed the efficacy of applying the competency-based approach to the entire family training program.

#### **Publications Resulting from This Research**

None reported.

### **[443] Predicting the Visual Abilities of Partially Sighted Persons**

**John Trimble, PhD**

Rehabilitation Research and Development Center, Edward Hines Jr., VA Hospital, Hines, IL 60141

**Sponsor:** VA Rehabilitation Research and Development Service (Project #C261-RA)

**Purpose—**Traditional measures of visual function such as visual fields, contrast sensitivity, color vision, acuity, and ocular range of motion are obtained using standardized stimuli presented under tightly-controlled conditions. These conditions are necessary to obtain reliable, reproducible, and consistent results. The measures themselves are of great value for diagnosing visual disorders and assessing the progress of medical or surgical treatments. However, despite their clinical value, these measures offer little in the way of predicting how well someone with severe visual impairments can perform ordinary everyday tasks. The purpose of this study was to determine which, if any, of these measures could be used to predict these abilities.

**Progress—**The initial plan was to isolate elementary behavioral components of visually-guided tasks and relate the performance of these behaviors to mea-

asures of visual function. However, breaking down complex visually-guided tasks into elementary behavioral components is a difficult problem. Therefore, efforts were concentrated on simple tasks like object discrimination and perceptual judgments like "complexity." Initial studies were concentrated on finding relationships between visual acuity, contrast sensitivity, and performance on the aforementioned tasks.

The results of these studies were largely inconclusive due to the high intersubject variability in the measures of visual function. Studies were refocused on the problem of determining the physical features of two-dimensional objects that affected perceptual judgments of complexity and similarity. Using a common technique of describing two-dimensional closed contours, a measure was developed that was highly correlated with people's judgments of the similarity and complexity of closed contours. The

measure was based on the Fourier transform of a function describing the tangent angle to contour's boundaries at regularly spaced intervals. This transformation yields a set of variables called Fourier descriptors and has been used successfully to solve many pattern recognition problems. The magnitudes and phase angles of the Fourier descriptors carry all of the information about the contour's shape and are invariant to rotation, translation, and scaling. A measure of similarity was derived between two contours by calculating the Euclidean distance between their Fourier descriptors. A measure of complexity was also derived by computing the energy in six equally spaced bands of Fourier descriptors.

**Results**—A set of six contours was created and their Fourier descriptors were determined. Thirty subjects were asked to rate the complexity of each form and the similarity of all pairs of the six forms. The subjects examined the forms visually and tactually. It was found that complexity ratings were highly correlated with high-frequency bands of Fourier

descriptors, regardless of how the forms were viewed. It was also found that the band of Fourier descriptors that was most highly correlated with subjective ratings of similarity depended on whether the form was viewed tactually or visually. Visual similarity ratings were more highly correlated with high-frequency bands of Fourier descriptors and tactual similarity ratings were more highly correlated with low-frequency bands. In addition, it was found that tactual ratings of similarity were highly dependent on the form's area. The data suggest that it is much more difficult to detect differences between small forms than large forms. Interestingly, this finding does not hold for forms that exceed a certain area which suggests that different perceptual mechanisms may be used for large forms.

#### **Publications Resulting from This Research**

**Physical Correlates of Tactual and Visual Perception.** Trimble J, Hollyfield R, Zuber BL, Abrams-Baroff S, in *Proceedings of the IEEE International Conference on Systems, Man and Cybernetics*, 396-400, 1987.

### **[444] Identification of the Dimensions of Vocational Rehabilitation Service Activity and Implications for Employment Outcome**

**J. Martin Giesen, PhD**

Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

**Sponsor:** *National Institute on Disability and Rehabilitation Research; Mississippi State University*

**Purpose**—The purpose of the research study is to answer the following questions: 1) What are the underlying dimensions of rehabilitation service delivery that can be derived from the variables in the National Blindness and Low Vision Database (a database including extensive case file information on approximately 1,000 people served by vocational rehabilitation agencies throughout the US)?; and, 2) How and in what ways do these dimensions or factors relate to employment outcome for people served by vocational rehabilitation agencies?

**Methodology**—A literature review was conducted on service delivery models and statistical clustering techniques. Service activity variables from the data base are being identified. A data analysis and interpretation of factors/clusters will be conducted.

**Progress**—Data analysis is in progress and results of the study are expected to be available later this year.

#### **Publications Resulting from This Research**

None reported.



#### [445] Identification of Differential Costs and Time Usage of Blind and Visually-Impaired Persons

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**William H. Graves, EdD; Corinne Kirchner, PhD; Lynn McBroom, PhD; Kathy Nelson, MS**  
Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University,  
Mississippi State, MS 39762

**Sponsor:** *National Institute on Disability and Rehabilitation Research; Mississippi State University;  
American Foundation for the Blind*

**Purpose**—The aim of this project is to answer the following research questions: 1) Are there differential monetary costs and time utilization patterns for blind and severely visually-impaired persons? 2) In what categories do these differential costs and time utilization patterns occur? and, 3) Are they associated with particular lifestyles, life stages, and environments?

**Methodology**—Two hundred and twenty-seven people with visual disabilities were interviewed in the four seasons of the year to reflect seasonal differences in activity and time usage. Each interview occurred on a different day of the week to reflect differences in time and money usage during the

work week and on Friday, Saturday, and Sunday. Like information was collected through interviews of 152 sighted, nondisabled peers to establish a comparison group. Information was collected on personal factors, role factors, environmental factors, and resource factors.

**Progress**—Collected data are being analyzed. Results of the data analysis will be interpreted in terms of the differential monetary costs and time utilization patterns for persons who are visually disabled as compared with their sighted peers.

##### **Publications Resulting from This Research**

None reported.

#### [446] Differential Costs and Time Usage of Blind and Visually-Impaired Persons and the Vocational Rehabilitation Process

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**William H. Graves, EdD; Corinne Kirchner, PhD; Lynn McBroom, PhD; Kathy Nelson, MS**  
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Mississippi State, MS 39762

**Sponsor:** *National Institute on Disability and Rehabilitation Research; Mississippi State University;  
American Foundation for the Blind*

**Purpose**—The purpose of this project is to answer the following research question: Are there relationships among the differential expenditures and time usage patterns associated with blindness and visual impairment and the rehabilitation process?

**Methodology**—Data are being collected through case file reviews and subsequent interviews of 120 blind or severely visually-impaired persons served by four public rehabilitation agencies in four states. Collected data will be analyzed and compared to

results from an earlier study of time and money usage patterns of people who are visually disabled in terms of rehabilitation contributions and in comparison with nondisabled persons.

**Progress**—Case file reviews and personal interviews are in progress and results of the study are expected to be available in late 1990.

##### **Publications Resulting from This Research**

None reported.

## [447] Sensory Aids for the Blind and Visually Impaired

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**Arthur Jampolsky, MD; John Brabyn, PhD; Deborah Gilden, PhD**

The Smith-Kettlewell Eye Research Institute Rehabilitation Engineering Center, San Francisco, CA 94115

*Sponsor: The Smith-Kettlewell Eye Research Institute; National Institute on Disability and Rehabilitation Research*

The following are summaries of some of the past year's projects of the Smith-Kettlewell Rehabilitation Engineering Center, with support from the

National Institute on Disability and Rehabilitation Research.

### SKERF-Pad Computer Access System

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**Purpose**—We have been engaged in the development of a revolutionary new method of computer access for the blind, using a touch-pad to represent the computer screen. The user merely touches any part of the touch-pad, and a speech synthesizer enunciates the contents of the screen at the corresponding point. The new system, named the SKERF-Pad, greatly simplifies computer use by the blind.

**Progress**—The current version of the system is now in use by ten outside evaluators, including a worker in the State Building in San Francisco and Mr. Harvey Lauer of the VA Blind Rehabilitation Center in Hines, Illinois. In addition, we have installed a SKERF-Pad on the IBM-compatible computer in our vocational laboratory to allow its evaluation in daily use by our blind engineers.

During the past year we have been making the SKERF-Pad program usable by a wider range of IBM-compatible computers—it will now work on PC, XT, and AT compatibles. It will work on color

screens and on most networking systems, and can use either of two commonly available speech synthesizers. A most significant additional development is the new touch-pad overlay, produced by vacuum thermoforming methods from a mold constructed to our design by Litzaw Engineering, Inc. The new overlay gives the device a very professional look. It guides the user's fingers along the lines of the screen via raised tactile markings, delineates the positions of individual characters, and provides a column of tactile switches for the control of various features of the system.

Our contractor on this project, William Loughborough, has made the current version of the system commercially available for \$500, including the touch-pad, overlay, and software. Meanwhile, other options are being explored for larger scale commercialization. A version is expected to be available soon through Edmark, Inc., of Bellevue, WA, which manufactures the Touch Window used in the SKERF-Pad.

### Smith-Kettlewell Volatile Braille Display

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**Progress**—Our new low-cost refreshable electromagnetic braille display has moved rapidly toward completion. Manufacturers have been engaged in the commercialization process.

A principal advantage of the design is the extremely low parts count; however, because the electromagnetic activation requires a separate coil

for each braille pin, optimization of coil design and identification of potential sources are current priorities. We are providing engineering assistance as needed to the manufacturers. We are retaining one prototype in our laboratories for continued testing and for resolving any problems encountered in the process of pre-production engineering.



## Flexi-Meter

**Progress**—The engineering prototype of the Flexi-Meter (our microprocessor-based job instrumentation system for the blind) has been substantially modified and upgraded during the past year. The firmware has been expanded to use most of the hardware capabilities and provide the ability to give desired outputs from a wide variety of instruments. Tests have been done on connecting the unit with various commercial transducers. As a demonstration of the unit's flexibility, the system has been adapted to read a wind direction and speed meter and has been fitted with custom thermometer and barometers. Thus, the unit now incorporates a basic talking

weather station. The ability to make the weather station adaptation in a short time period has confirmed the Flexi-Meter's potential as a customized instrumentation system for measuring any parameter.

The unit has been demonstrated to a number of blind persons and their feedback has been taken into consideration in the design of the eventual production unit. Only minor physical design changes were considered necessary by those who have tested the unit and those changes will be incorporated into the final version. The production engineering stage of the Flexi-Meter is now underway.

## Braille Note Taker

**Final Results**—Our Note-a-Braille (Electronic Braille Notetaker) project has been completed as scheduled. Two versions are now commercially available: one manufactured in the United States and one manufactured in England.

In the spring of 1988, HY-TEK Manufacturing, Inc. of Sugar Grove, IL, began marketing the Smith-Kettlewell Note-a-Braille II. This version of the device comes with a parallel-to-serial converter (needed for most standard brands of computer) and has an expanded memory of 16K. It is being offered in the latest catalog of the LS&S Group, Inc., Northbrook, IL.

The English version is being made by the manufacturers of the Brade Speech Synthesizer in England. It is ideally suited to the very popular BBC computer; no converter is needed to interface the Note-a-Braille's natural parallel port to a serial port on the BBC instrument.

The successful conclusion and commercialization of this project has resulted in a unique, low-cost electronic braille note-taking system being made available to the blind. The design offers an affordable alternative to the expensive special-purpose braille word processor/computer systems.

## General-Purpose Stored-Speech Board (Nattering Ram)

**Purpose**—A new project this year has been the development of an inexpensive general purpose add-on speech module. We have long seen the need for an addressable limited-vocabulary speech board to exist as a component of talking devices. A generic voice module (GVM), using a commercial synthesizer chip, is made by AFB and marketed as the GVM. This is useful for adapting certain commercial products which have a suitable signal output to drive it; however, application of the GVM is limited to a particular class of special modification. A more general approach is needed to fulfill the following functions.

First, it appears that the product life of speech boards for commercial applications has been shorter than that of talking devices for the blind. With the demise of both the TSI Mini Speech Board and the National Semiconductor Digitalker chip set, useful talking meters and calculators have disappeared with them. (There is now a crisis in the area of talking instruments for the blind: no talking multimeter is currently available, even though the demand for such meters numbers about 150 per year.) Our generic unit will always exist, since it is made from the most basic computer memories and logic chips.



Second, such a component will not be language-specific. Its vocabulary is loaded by speaking into a microphone; in fact, one version, which we recently described in detail in the *Smith-Kettlewell Technical File*, includes the ability to record the speech yourself. (The do-it-yourself version uses a battery-backed RAM; it is trivial to make a nonvolatile version recorded in the laboratory.) Although the current design contains fourteen chips, most of these cost less than a dollar, and the eventual price will be low.

**Results**—A 16-word, randomly-accessible speech module, named the Nattering Ram, has been developed and its design published in the *Smith-Kettlewell Technical File*. Along with a Technical Devices voltmeter chip, the device makes it possible to replace the defunct talking multimeters (work is now proceeding on this application). Details on a first-in first-out (FIFO) buffer have been published in our *Smith-Kettlewell Technical File* so that others, including the enterprising blind do-it-yourselfer, can use the Ram-Talker to make other talking instruments.

### Temperature-Controlled, Quick-Heating/Fast-Cooling Soldering Iron

**Progress**—A successful temperature controller for the so-called Fingertip Soldering Iron has been designed, evaluated by our three blind laboratory workers, and published. Three prototypes have been built for field evaluation.

A rudimentary design for this fingertip iron was submitted in writing by B. Vinther. It uses a soldering tip from a cordless battery iron to make an extremely lightweight iron which puts the user's fingers close to the work—thus enhancing facility in handling the device. A further advantage is that such a tip can be placed on the work when it is cool

and then energized by way of a foot control. A serious disadvantage of the original instrument was that frequent overheating of the tip was inevitable. Our newly designed temperature controller completely solves the problem; the tips last longer and damage to the work is now infrequent. The controller works by measuring the resistance of the tip, which is an element of a Wheatstone Bridge.

The new design is published in the *Smith-Kettlewell Technical File*. Mr. Vinther is planning to manufacture the device.

### Carpenter's Level

**Purpose**—Our project to develop an improved Auditory Carpenter's Level is being successfully concluded. We identified a commercially available electronic level which lends itself to convenient adaptation for the blind. Difficulties and design alterations accompanying a takeover of the original level manufacturer by another company were resolved. Four prototype levels were duly constructed and distributed as planned and the feedback was all positive.

**Progress**—In 1988, engineers from the National Research Council of Canada visited our laboratories for an extended period to study our vocational engineering methods and our circuit construction techniques for blind engineers. After reviewing our circuits for the level (including information we obtained through reverse engineering), they derived

a simplified version which they intend to implement for producing equivalent units.

Our original approach had been to make all of the visual level's LEDs audible to the blind user; this was done by way of an external oscillator that generated four different pitches. The simplified approach being adopted by the Canadians for the production units is to modify the response of an internal beeper; the level will emit a solid beep at one side, silence will occur on the other side, and the beeper will pulsate when the desired position is attained. A survey of our users suggests that this arrangement would be slightly less preferable to our audible presentation (it will not indicate the degree of tilt, for example), but that the new version would be adequate. The production version should, however, be less expensive than our earlier, more comprehensive version.



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## Stud Finder

**Purpose**—A common problem encountered by custom cabinetmakers, as well as individual homemakers, is finding the structural members (studs) within walls onto which heavy shelves and wall hangings can be mounted. There have been many devices for finding studs, but these are traditionally visual instruments. We have successfully modified a commercial stud finder to present auditory feedback to the blind cabinetmaker and handyman.

**Progress**—The Zircon Stud Sensor (also marketed by Radio Shack as the Archer Studfinder) is a sophisticated electronic device whose indications of hidden structures are not subtle. It is a relative capacitance meter which senses these structures by their capacitance effect; it presents these relative

indications to a sighted user via a column of LEDs. By reverse engineering, a relative capacitance analog signal was found that can be used to drive a voltage-controlled oscillator (VCO). Thus, with our modified instrument, the blind user hears a distinct rise in pitch when the capacitance increases—which happens when a stud is found.

**Future Plans**—Four prototypes were made for field trials. The device will be made available through the privately funded Rehabilitation Engineering Service if user feedback is positive. The modifications have been published in the *Smith-Kettlewell Technical File*, and individuals who have made their own from our design have applauded the instrument's utility.

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## Non-Damaging Low-Resistance Ohmmeter

**Purpose**—Traditionally, ohmmeters for the blind have used a Wheatstone Bridge whose output was simply detected auditorially. (The bridge configuration has a traditional preference because its output is linear; the output of other ohmmeters is not.) The problem with this technique is that low resistances under test are subjected to high currents (as much as 1 amp for a 1-ohm resistor). While necessary to make the bridge output sufficiently audible, these high currents can be damaging to modern components. Such an instrument cannot safely be used for tracing circuit boards, which is a significant loss for the blind service technician who cannot trace circuit boards by eye.

**Progress**—Using a sensitive comparator chip, the National LM311, we designed an audible Wheatstone Bridge circuit that subjects its test element to 10 mA, maximum. Furthermore, it is silent until a test resistance below its preset threshold is present across its terminals. Thus, not only will it serve as a much needed ohmmeter, but tracing of moderately sensitive circuitry is now possible.

**Results**—The device has been successfully built and tested, and is being published in the *Smith-Kettlewell Technical File* as well as added to the range of products of the Rehabilitation Engineering Service.

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## Auditory Breakout Box

**Final Results**—We have made several improvements to the Smith-Kettlewell Auditory Breakout Box, and have completed its transfer to production this year.

We investigated a number of alternatives for the jacks used on the box and selected an inexpensive eyelet. In addition to the low cost, the eyelets can be soldered directly to a printed circuit board.

To this end, we designed a PC board to hold the eyelets and to function as the cover of the box. Also, a second PC board was designed for the circuitry of the box. The redesigned Breakout Box is now commercially available through our Rehabilitation Engineering Service.

## Low-Cost Blood Pressure Monitor

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**Results**—Resulting from a number of inquiries from the field and complaints by medical personnel regarding the accuracy of automatic digital sphygmomanometer, we have developed a low-cost auditory blood pressure gauge.

The new device uses the traditional stethoscope measurement technique (although the stethoscope is not needed for measuring one's own blood pressure), and has two buttons which the user pushes at the instant that pressure passes the systolic and diastolic points. These points are stored with internal circuitry. Readout of the systolic and diastolic levels is accomplished using a movable pointer on it

with a Braille dial that is moved until an auditory tone reaches a null point. If desired, a talking readout of blood pressure can be obtained by interfacing the device with the Nattering RAM/multimeter (described above). This configuration has also been tested in our laboratories.

The system is extremely inexpensive, requires no specialized synthetic speech circuitry, and is expected to be suitable for potential use by medical personnel. Evaluation is being carried out in conjunction with the Presbyterian Pacific Medical Center.

## Flexi-Formboard

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**Final Results**—Adaptive Communications Systems, Inc. has incorporated the following design modifications into the Flexi-Formboard: 1) the underside of each shape template is now covered over to allow for a blank space on the board's surface. This provides a place for each template on the board at

all times, thus preventing the loss of pieces which earlier had to be placed alongside the unit when not in use; and, 2) the height of the templates was decreased to make them more of an integral part of the board's surface. The Flexi-Formboard is now entering commercial production.

## Tact Tell Map

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**Results**—During 1988, Martin S. Michael, a San Jose State University graduate student, completed the Tact Tell Map. This required making modifications to the system he had fabricated the previous year in response to both alpha and beta test site evaluations. All alpha site evaluators were adults, and their comments resulted in software modifications.

These tests were conducted at the School for the Blind in Fremont, CA. The students involved were blind or had low vision but had normal motor skills. They were at a third grade, sixth grade, and high school level.

The Tact Tell Map is now back in the Smith-Kettlewell laboratories. Within the past month we have made one hardware modification and several software modifications. The hardware modification was done in response to difficulties experienced by low-vision individuals in seeing where to place the puzzle pieces on the map. This was easily remedied

by repainting these surfaces a flat light gray to provide contrast against the shiny blue of the surrounding oceans.

Included in the new software improvements are: 1) faster boot-up procedure; 2) improved pronunciation through an Echo Speech Synthesizer; 3) virtually instantaneous feedback in response to the user's answers; 4) positive feedback on the screen backed by a flashing window; 5) music played during the time the user is to remove all pieces prior to beginning the game; 6) music played as part of the positive feedback at the end of the game; and, 7) the beginning of an authoring system has been added.

This last feature adds flexibility to the system, which is vital to its use in the classroom. It will allow the teacher to have the system pose any question at any time as long as the puzzle pieces answer them. For example, questions which have the United States as their answer could vary from "insert the country whose capitol is Washington,



DC," to "find the country where baseball is the national pastime."

A large variety of concepts can be learned from this system, some of which are: 1) many geographic, cultural, and demographic concepts about the six areas represented by pieces in this puzzle can challenge the student. Anyone who knows BASIC can alter the questions asked by the system; 2) the student can learn relative locations of the geographic areas and their shapes; 3) sighted children can learn basic colors, since there are five of them used on the pieces; 4) they can learn the concept of puzzles and

how to work with them; 5) students can learn the fundamental operator skills needed to start a small computer; and, 6) the first experience with a teaching machine is made more enjoyable because the lessons are given in a game format. The system can develop fundamental skills needed to work with a teaching machine, such as following specific directions in the given amount of time.

The teaching system can naturally incorporate these skills in a child's repertoire through playing a game with the computer.

## Dexter: A Mechanical Fingerspelling Hand for Deaf-Blind Users

**Progress**—During 1988, Dr. Deborah Gilden, PhD, of our staff, and Ms. Lindsay Gimble, Certified Interpreter, analyzed the accuracy of Dexter's hand configurations for the various letters of the one-hand manual alphabet. In addition, they initiated a determination of the sequence of individual finger movements required to achieve smoother letter-pair transitions. Mr. David L. Jaffe of the Palo Alto VA Medical Center modified the software to incorporate these improvements.

Overlapping these activities was the design and fabrication of Dexter II, another mechanical fingerspelling hand. As with the original Dexter, this new hand was a class project conducted by graduate students at Stanford University Department of Mechanical Engineering, although this time the financial support was provided by the VA rather than by Smith-Kettlewell. Smith-Kettlewell, however, served as the consultant to this project.

**Results**—The Dexter I system offers the following features: 1) large hand; 2) machined aluminum fingers and palm; 3) pneumatically-driven with actuating equipment and valving housed in two separate assemblies; 4) approximately 2 letters/sec; and, 5) pauses in neutral position between letter pairs. In comparison, features of the Dexter II are as follows: 1) hand the size of that of a 10-year-old

girl's; 2) Delrin fingers with a sheet aluminum palm; 3) DC servomotor driven with driving circuit, etc., housed in one compact unit; 4) approximately 4 letters/sec; and, 5) pauses to hold letter position and moves through neutral between pairs.

Dexter II has been shown to members of the deaf-blind community in the San Francisco Bay area. Most users tried it either during a demonstration at a camp for deaf-blind people or at a local social deaf-blind club. Within brief exposure periods, it was demonstrated that Dexter could be read tactilely by those used to receiving tactile fingerspelling. For most users, the system could present letters at a rate more rapid than the user could receive, except for one individual who is a very fast fingerspeller receiver. Thus, Dexter II's presentation rates appear adequate.

**Future Plans**—In 1989, we identified a potential manufacturer for the fingerspelling hand. Mr. Brad Smallridge, of Upstart Robots, Inc., San Francisco, is now engaged in the development of Dexter III, with a view to commercial production. Dexter III will incorporate a number of improvements over Dexter II, including a more anatomically accurate implementation of the hand capable of forming all letters of the fingerspelling alphabet in a more natural fashion.

## TeleBraille

**Purpose**—The TeleBraille is a communications device for the deaf-blind. This commercial unit has

gone out of production, necessitating the design of an updated system. The TeleBraille was the only



device available in this country that allowed the deaf-blind to communicate with other people through phone lines. As many states now have programs which supply telecommunication devices for the deaf (TDDs) for deaf and deaf-blind users, there is a significant need for a replacement TeleBraille.

**Progress/Methodology**—We have been canvassing the needs and desires of the deaf-blind community to determine the features and improvements which need to be incorporated in any new device. The original unit includes a face-to-face mode for direct interpersonal conversation. There is general agreement that this, along with other features, should be incorporated into our new design.

## Usher's Syndrome Studies

**Purpose**—Dr. Lea Hyvarinen, MD, ophthalmologist in the field of low vision and deaf-blindness, joined our staff for a 6-month study of vision assessment methods in the deaf-blind population. The study had two principal goals. The first was to study and recommend better techniques for the communication process among the eye specialist, the deaf-blind patient, and the interpreter during the eye examination. The second was to better characterize the functional visual deficits in this population, especially those associated with Usher's syndrome, and to devise improved tests to measure these deficits.

**Progress**—A major task was patient recruitment and scheduling, in which we were assisted by the cooperation of the Helen Keller National Center and the Oakland Lions Blind Center. Financial assistance was also received from Boy's Town, Omaha, Nebraska.

During the course of the study, over 30 patients with various degrees of visual and auditory impairment were examined. The examining sessions were all videotaped for subsequent analysis. The examinations included such traditionally standard tests as: 1) visual acuity (distance and near); 2) smallest text read (m-scaled); 3) Goldman field test; 4) D-15 color test, Adams desaturated; 5) accommodation test;

We have also begun a study of existing TDD technologies, and have enlisted the cooperation of Ralph Krongold of Krown Research, Inc., a manufacturer of TDDs. We have been able to evaluate a special modem manufactured by his company that could well be incorporated as the heart of a new TeleBraille. Contacts are also being made with other makers of TDDs to determine the applicability of their products and their interest in assisting us in this project.

For the software development needed for the implementation of the TeleBraille control structure, Archimedes Software of San Francisco has allowed us to use a copy of their SIMCASE system without charge and has offered to provide documentation on floppy disk.

and, 6) retinoscopy. Nontraditional tests included: 1) LH5 contrast sensitivity test; 2) Cambridge low contrast gratings; 3) flicker sensitivity; 4) glare recovery; 5) balance test; and, 6) effects of yellow filters. Tests used only on a sampling of the patients included hearing tests, lip-reading tests, flicker fusion at different luminances, and spectral sensitivity.

**Results**—The result was a more comprehensive body of vision test data than has hitherto existed on this population, and which will enable a better understanding of the course and nature of the complex vision impairments which result from these diseases. These data are still being collated and analyzed for publication. Another result was the identification of the most appropriate tests for future clinicians to use with these patients—including certain tests which may facilitate discrimination among the different types of Usher's syndrome (hitherto a very difficult task).

In the realm of improving communication methods, the taped exam sessions were edited and synthesized into a training videotape for interpreters, while training manuals for interpreters and patients were written.



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## A Study of Mobile Subjects

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**Purpose**—The goal of this study is to characterize the information needed for mobility so that future generations of electronic travel aids for the blind can be based on a sounder understanding of the problem.

**Progress**—A study of mobile subjects was completed. Five experienced and skilled blind travelers were asked to follow a 12-block route leading through both familiar and unfamiliar areas and encompassing both an urban shopping area and a residential neighborhood. Subjects were asked by the experimenters to report all information they perceived and used for guiding their travel, and also to describe how each piece of information was perceived or derived. This information was recorded on tape as a running commentary as the subject moved along the route. Remarks of the experimenters were also recorded and consisted mainly of directions to the subject and interrogation to clarify the subjects' remarks. After each trial, the subjects were debriefed in a recorded interview session in which they were asked to identify any additional information they would like (in an ideal world without consideration of what might be available or of expense) to receive during travel. The commentaries were transcribed and scored using a scoring

system devised by Emerson Foulke, PhD, our collaborator on this project.

**Final Results**—To give an idea of the types of analyses which this approach allows, an example of data from a subject can be broken down into perceived facts, remembered facts, and inferred facts. The latter two categories are much more numerous on the familiar part of the route than on the unfamiliar. Many alternative analyses can be used to yield objective data on many aspects of cues used during travel, with particular emphasis on the source of each piece of information enunciated by the subject—whether via hearing, touch, memory, deduction, etc.

We believe this study represents the first systematic analysis of what information skilled blind travelers actually use for orientation and mobility. This gives a firm idea of what information would be redundant in a travel aid and what is achievable as a maximum level of performance of mobility only with a long cane. It will serve as a baseline for the development of travel aids and mobility training programs. The results will be fully collated and published in professional journals to ensure their availability to other researchers and mobility aid developers.

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## Intersection Crossing Experiment

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**Purpose**—One of the features arising from the mobility study was the surprising tendency of even experienced blind travelers to make mistakes regarding the type and operation of intersection controls and to make occasional unsafe crossings—e.g., crossing on a red light and/or when cars were approaching. In our debriefing of the subjects, a frequent comment was that more information about the nature and status of intersections would be a most helpful piece of additional information which might be included in future travel aid outputs. Certainly, the amount of time spent by the subjects

waiting at intersections (especially the relatively quiet and unfamiliar ones) appeared to be large.

**Methodology**—As a pilot study to examine this problem further, we asked three experienced blind travelers to cross certain intersections repeatedly, while the researcher timed the delay between the lights turning green and the subjects' beginning the actual crossing. We also noted any unsafe crossings. In our first pilot study the average delay was 10 seconds, but varied widely from 2 to 65 seconds. Three unsafe crossings were recorded.



## Simulation Studies of a New Navigation Device for the Blind

**Purpose**—Our strategy for the design of new travel aids involves simulation to avoid having to build expensive hardware and to maintain greater flexibility. Our method is to simulate the aid by having an experimenter present the desired information (manually, auditorially, etc.) to the blind subject as he travels. We have implemented this approach in a feasibility study for a new type of travel aid being developed in collaboration with Ron Milner of Applied Design Concepts, Inc., Grass Valley, CA. This research dovetails with our basic mobility studies outlined above, which have already provided clues as to the types of information it is desirable to present.

The Navigator is a proposed device which will be worn by the traveler and require no installed transmitters. Sensors would monitor direction and distance traveled and an internal microprocessor will use this information to calculate the user's position along a pre-recorded route. Verbal human descriptions of relevant environmental features pre-recorded by a sighted traveler traveling the same route at an earlier time will be available upon request (by pressing a button) at any point along the route, as will certain other information such as direction of travel and distance to and from the nearest intersections. Spontaneous announcements from the device will accompany any deviation from the route and any dangerous veering at intersections. Tones will sound automatically at important points such as intersections to suggest good times for the user to request more detailed information about the route.

**Methodology**—We simulated this system using a dummy device carried by the subject. The device incorporates four pushbutton switches connected to a beeper. The subject can interrogate the simulated navigation aid (the researcher) by pressing the buttons to request different types of information. The experimenter can tell which button (No. 1 to No. 4) was pushed. If the subject pushes Number 1, the experimenter knows he is to tell the subject how far it is to the next intersection; if Number 4 is activated, the experimenter knows he is to give a running description of all the relevant features of the nearby environment as outlined above.

**Results**—A total of 12 blind subjects tested the simulated Navigator system. We traveled a number of trial routes with our blind consultant, Monica Schaffer, who was selected as a typical blind pedestrian with average travel skills. Her comments were used in deciding on the command set for the simulated Navigator system; namely, "from," "to," "direction," and "description."

Three blind subjects with travel abilities varying from poor to excellent then used the simulated system over various local routes including familiar and unfamiliar areas. Their comments were noted in the form of answers to questions regarding the potential usefulness of the system in different situations. Overall, comments from this group indicated considerable interest in the system, especially as a training aid, but reservations were expressed regarding its usefulness on familiar routes, potential size and weight of the device, and the problem of getting the tapes made. The most skilled traveler of the group thought the potential to provide a detailed description of the route was valuable, as was the elimination of the user's need to count streets in order to keep track of his location. When asked what such a device should sell for, this group gave answers ranging from \$200 to \$1,000, with a mean price of \$570.

These comments were used to refine the protocol to use a standard 5-block route including residential and shopping areas, and to devise a formal questionnaire to be administered at the end of the trials. Seven more subjects were run through the standardized route and answered the questionnaire. In each case, in addition to the questions on the potential utility of the device, data on the subject's age, number of years since becoming blind, amount and type of mobility training, years of experience in independent travel, and an assessment of overall travel skill were recorded. The subjects were all in the 18 to 40 age group and included a spread of travel abilities ranging from poor to good. The questionnaire and a summary of responses are available from our Rehabilitation Engineering Center.

The subjects' responses were more positive than expected. Most thought they would be willing to buy such a device, and that it would make a difference



to their travel. Most, however, thought it would be somewhat difficult to get a sighted friend to record the necessary tapes for them. If a free service providing such tapes were available, all said they would use it.

The study is now complete with external funding from Applied Design Labs which, with support from us as subcontractors, will study the feasibility of the new device.

## **Pediatric Vision Screening Research**

**Results/Implications**—We have completed a field study of the accuracy of our Polaroid photorefractive device. In this study, the adapted camera was tested for an extended period in a pediatric clinic, and in our own pediatric laboratory. Results of Polaroid photorefractive of 85 infants were compared to the refraction obtained by a pediatric ophthalmologist using retinoscopy under cycloplegia. This study indicated that the camera is sufficiently sensitive to be used as a mass screening device. It has allowed detection of previously overlooked potentially blinding impairments in a number of cases.

Another achievement during the past year was the completion of an optical analysis of image formation in photorefractive. This was accomplished in collaboration with Dr. Wolfgang Wesemann, PhD. Through this analysis and our practical experience with the Polaroid device, we have determined the necessary parameters for accurate calibration

of the camera and for achieving the desired sensitivity for screening.

The analysis also suggested that the design tolerances of photorefractors and the scoring of photographs is sufficiently critical to preclude a simple universal camera attachment (to fit any camera) that would be sensitive enough to be truly useful. We have therefore suspended activity on that aspect of the project to concentrate on the refinement of the successful Polaroid version. We envisage the principal application of our device to be in pediatric clinics where early vision screening is presently rudimentary at best. Our new device will offer the potential, at very modest cost, for every pediatrician to conduct effective early detection of potentially blinding vision impairments as a part of his routine well-baby checkups. Considerable potential also exists for use in areas of the country (and the world) where vision specialists are seldom available.

## **Battery-Powered Multipurpose Lighting System**

**Progress**—In collaboration with Alan Lewis, OD, PhD, we have designed, built, and tested a head-mounted, battery-powered, low-voltage, high-intensity supplementary lighting system for use in reading and other near tasks—suitable for both low vision and more general (e.g., surgical) applications. The beam size is calculated to illuminate a page-sized area at normal reading distances.

**Results**—We have conducted careful laboratory tests and measurements on the prototype, including a comparison test with a high-intensity, spectacle-mounted light used in ophthalmology. The light output of our system exceeded that of the comparison

device by a factor of 20, providing two-and-one-half times the intensity and eight times the beam coverage, while using only twice the power. The luminance of typical reading material was measured at 1000 candelas per meter squared for normal reading distances—representing approximately 10 times that resulting from normal ambient room lighting. The unit thus provides a very useful increment in available light for the low vision user in reading and other near tasks. It is well known that such an increase in lighting level greatly improves the reading abilities and comfort of most low vision patients, and even that of elderly persons with normal vision.

## Spectacle-Clip Illuminator

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**Purpose**—A new project for this year has been the development of a spectacle-clip illuminator for the many low vision patients who read using high-powered (+20 to +40 diopter) spectacle lenses—resulting in a reading distance of approximately 1 to 2 inches. The problem faced by this population is that when the reading material is held up to the eye, the head at least partially blocks any ambient illumination, making reading difficult.

**Results**—Our solution to this problem uses a small

1- to 2-watt light bulb and reflector which clip onto the user's spectacles in such a way that illumination is projected on objects held within a few inches of the spectacle lens used for reading. Our most satisfactory prototype to date uses a small cylindrical reflector in which are mounted two miniature krypton bulbs consuming approximately 1.8 watts. Initial testing has confirmed our predictions regarding the required light intensity, and the device produces a dramatic improvement in brightness of reading material in all indoor conditions.

## Fiber-Optic Illuminator for Use with Hand-Held and Stand Magnifiers

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**Progress**—While battery-powered incandescent or fluorescent systems have been used in some hand-held and stand magnifiers to help boost light intensity on the subject matter, they often provide insufficient light for low vision persons with high illuminance requirements. To address this problem, our consultant, Dr. Alan Lewis, designed a high-

intensity lighting system using a highly efficient 70-watt metal-halide source (>70 lumens/watt), fiber optics to deliver the light to the magnifier, and a three-mirror optical system in combination with a Fresnel lens to distribute the light on the work surface.

## Low-Contrast Acuity Charts

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**Progress**—We are now in the evaluation stage of our project to develop an innovative low-contrast acuity chart for the rapid measurement of visual contrast sensitivity. Detection of low-contrast and low-luminance targets are important parameters in assessing the functional vision in those with low vision and existing tests are inadequate. The new concept combines the measurement of low-contrast and low-luminance vision performance into an eye chart of proprietary design, allowing a single rapid test of the patient's visual performance under conditions of reduced contrast and luminance.

**Results**—We have now produced both near and distance versions of this chart. The near version was developed this year using the just-available New

York Lighthouse near-vision chart as a starting point in order to facilitate direct comparisons. Dr. Eleanor Faye of that organization made early copies of the chart available to us for this research. We reprinted the chart with black letters on a dark gray background and calibrated the resulting contrasts in our laboratories using a photometer.

The new charts have been tested by Gunilla Haegerstrom-Portnoy, OD, PhD, in collaboration with the U.C. Berkeley Low Vision Clinic, using patients with early age-related maculopathy (ARM) and an age-matched control group with normal vision. A summary of these results appears in our *Annual Report of Progress* and indicate that the new test is a much more sensitive stress test for the visual system than earlier acuity charts.



## Low-Vision Reading Performance Study

**Purpose**—We extended the low vision reading studies begun last year in order to address the parameters of reading performance relating to low vision aid design.

**Progress**—Following the preliminary pilot testing carried out last year, we substantially modified the experimental set-up in order to more accurately replicate the paradigm used by our consultant, Gordon Legge, PhD, with whom we have corresponded on the details of experimental procedure. Our goal was to extend Dr. Legge's work to a wider low vision population, especially including those with macular disease, and to explore the interaction of reading performance with a variety of other variables.

The study, now complete, addresses the question of minimum window size required for the efficient reading of scanned text—a vital factor for

the optimal design of CCTV reading systems. We wished to determine whether Dr. Legge's result (that reading speed is unaffected by window sizes greater than four letters) is applicable to the more commonly-occurring eye disorders such as macular disease.

**Results**—Our results indicate that reading speed indeed continues to increase significantly with window size well beyond the four-letter level. The results are consistent with Dr. Legge's results in that the latter used letters subtending a six-degree visual angle (i.e., very large print) for all subjects. With print of this size a window of four letters is all that is needed. With smaller more commonly used print sizes and magnifications, reading speed continues to increase up to at least a ten-letter window size.

Full results and conclusions are now being prepared for publication. The study is carried out by Patrice Archambault, MD.

## Hybrid Fresnel-Conventional Magnifier

**Results**—The feasibility study for our Fresnel-Conventional low vision reading magnifier is complete. (The concept of this device is to combine the advantages of clarity and high contrast provided by conventional optics with the light weight and wide field of view made possible by Fresnel technology.)

Our conclusions, based on evaluation by August Colenbrander, MD, of our Low Vision Clinic and on our in-house laboratory tests, are that such a device would be useful for reading large materials such as plans, maps, blueprints, etc. Another application is in reading material such as magazines in which text is arranged in columns and interspersed with pictures. The high-definition central field corresponds neatly to column width, while the Fresnel periphery allows rapid and convenient orientation and scanning. Another potential advantage appears to be in eccentric viewing, allowing an aiming point to be established and marked on the Fresnel part of the magnifier.

**Future Plans/Implications**—We concluded that a lens of this design does indeed have potential applications for low vision and is worth exploring

for commercial potential. Inexpensive manufacture would naturally be desirable and we have found a potential short-cut in this regard. With the help of our consultant, Dr. Wolfgang Wesemann of the University of Hamburg, we have tested a new Fresnel lens of German manufacture which may offer sufficiently high resolution and contrast to obviate the need for the conventional center lens in most applications.

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- Photographic Screening for Factors Leading to Amblyopia.** Day SH, Norcia AM, *Am Orthopt J* 38:51-55, 1988.
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#### [448] Identification of Differential Characteristics of Sites Selected or Rejected by State Licensing Agencies for the Operation of the Business Enterprise Program

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**Sponsor:** National Institute on Disability and Rehabilitation Research; Mississippi State University

**Purpose**—The purpose of the study is to address the following research question: Is there a relationship between sites selected and sites rejected for operation of Business Enterprise Program (BEP) facilities and the geographic location, size of business, and additional site and agency characteristics?

**Methodology**—A review of the literature on site selection standards used by state licensing agencies in the administration of the Business Enterprise

Programs and similar private business enterprises was conducted. The literature addressing the relationship of site selection standards to the career development of blind and severely visually-disabled persons was also examined. State licensing agencies from four states chosen from two RSA regions which represent both large and small BEP programs participated in the study. Data were collected from the state licensing agency records with reference to site selection, and BEP directors were interviewed.



**Progress**—Collected data have been analyzed using appropriate univariate and multivariate analysis techniques. Interpretation of the data analyses and report development are in progress and results of the

study are expected to be available shortly.

#### **Publications Resulting from This Research**

None reported.

### **[449] Identification and Classification of the Career Transition Problems of Blind and Visually-Impaired Youth in Transition from School to Work**

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Rehabilitation Research and Training Center on Blindness and Low Vision, Mississippi State University, Mississippi State, MS 39762

**Sponsor:** *National Institute on Disability and Rehabilitation Research; Mississippi State University*

**Purpose**—The purpose of this project is: 1) to identify and classify the career transition problems of blind and visually-impaired youth in transition from school to work; and, 2) to outline strategies which can be used by youth agencies, service providers, families, and employers to assist youth in making successful transitions.

**Methodology**—Sample data were collected from two service agencies which are noted as having successful transition programs for youth who are blind and visually-impaired. At each site, interviews were conducted with administrative personnel; service providers such as rehabilitation counselors, orientation and mobility specialists, and vocational instructors; parents; youth who are blind and visually-

impaired; employers; and community support personnel.

**Progress**—Qualitative analysis of the collected data is in progress. A taxonomy to define the career development problems faced by youth in their transition from school to work in terms of mastery of career development tasks is being developed. A conceptual framework linking strategy to career development problems is being formulated and results of the study are expected to be available this year.

#### **Publications Resulting from This Research**

None reported.

### **[450] Functional Vision and Clinical Tests in Low Vision**

**Ian L. Bailey, OD**

University of California, Berkeley, CA 94720

**Sponsor:** *National Eye Institute, National Institutes of Health*

**Purpose**—Our broad objective is to improve the quality of low vision care. The clinician attempting to help the low vision patient needs to have clinical tests that can predict the patient's disability at functional tasks.

**Methodology**—In this project, a battery of clinical tests and a series of tests of functional vision will be assembled. These tests will be applied to two groups of subjects who show substantive changes in functional ability with changes in illumination. One

group will have macular degeneration, the other retinitis pigmentosa. An added normal, age-matched control group will also be used. Controlling illumination will provide changes in the subjects' functional disabilities. Clinical test scores associated with particular levels of disability will be determined for each subject. The strength of the association between test scores and disability levels will provide the predictive power of the clinical tests.

The functional tasks emphasized are reading and face recognition. Clinical tests include: 1) visual

acuity: grating, letter charts, work reading, and low contrast letter charts; 2) contrast sensitivity: contrast sensitivity function of small and large field, edge detection, and Bailey's contrast edge test; 3) visual fields: Dicon perimetry, Amsler grid, and reversed contrast tangent screen; and, 4) reading eye movements: an infrared scleral reflection eye movement monitor will be used to record saccade rate, saccade length, and regression rate when reading different size print.

Correlations and multiple correlations between clinical test scores and functional abilities will be evaluated. Recommendations will be made advising clinicians which tests are most appropriate for predicting capabilities at the different functional tasks.

#### **Publications Resulting from This Research**

None reported.

### **[451] Vibrotactile Spatial Information for Sighted and Blind**

**William Epstein, PhD**

University of Wisconsin, Madison, WI 53706

*Sponsor: National Eye Institute, National Institutes of Health*

**Purpose**—The general long-term objective is to determine whether the potential information in dynamic vibrotactile transformation patterns can effectively communicate reliable descriptions of three-dimensional (3-D) structures and events in 3-D space. Realization of this objective will have important bearing on theoretical as well as applied matters. On the theoretical side, the research will have implications for the hypothesis of amodal information for perception, the nature of perceptual learning, and matters pertaining to cognitive representation. On the applied side, this work will provide a solid foundation for establishing the value of vibrotactile stimulation as a substitute for vision in the life of the congenitally blind.

**Methodology**—Congenitally blind persons and sighted persons will be studied in a series of experiments that present vibrotactile transformation patterns to the fingertip(s) of the percipient. The vibrotactile transformation patterns will be designed so that in principle they can specify 3-D structure and motion.

Adaptations of methodologies developed in the vision literature will be applied to determine if these patterns can elicit (either spontaneously or by a process of learning) reliable and accurate descriptions during on-line processing and useful cognitive representations (imagery) off-line.

#### **Publications Resulting from This Research**

None reported.

### **[452] Horizontal Light Path Vision-Enhancing System**

**Henry A. Greene, OD**

Ocutech, Inc., Chapel Hill, NC 27514

*Sponsor: National Eye Institute, National Institutes of Health*

**Purpose**—This is a clinical trial involving an experimental and control group to determine whether visually-impaired patients prefer the Horizontal Light Path Vision-Enhancing System (HLP-VES) over a comparable conventional bioptic telescope system currently available.

The experimental design will address factors of

appearance, weight, and field of view which have been shown to be important factors for the enhanced acceptance of such bioptic telescope low-vision devices.

The HLP-VES, a departure from conventional low vision aids, features its option arranged across the front of an eyeglass frame rather than protrud-



ing outward and forward. This superseded configuration adversely affects both appearance and weight.

**Methodology**—The controlled clinical trial will be run as a 4- to 8-month double crossover study at three clinical sites. The study will select and follow 120 adults with low vision who either are currently

using an existing device or are candidates for such a device. The study will also identify factors which will enhance the design and performance of the HLP-VES device.

#### **Publications Resulting from This Research**

None reported.

### **[453] Autofocus Telescope System for Low Vision**

**Henry A. Greene, OD**

Ocutech, Inc., Chapel Hill, NC 27514

**Sponsor:** *National Eye Institute, National Institutes of Health*

**Purpose**—Ocutech proposes to develop an autofocus telescope that can be mounted onto an eyeglass frame for use by the visually impaired. The design of the device will address the major complaints of users of conventional low vision bioptic systems regarding field of view, weight, and appearance. The proposed device will be derived from our current work on the Horizontal Light Path Vision-Enhancing System (HLP-VES). The HLP-VES is a manually focusing keplarian telescope that successfully addresses the acceptability issues noted above and appears to lend itself to the application of autofocus technology.

Initial efforts will adapt promising autofocus

hardware and software to the specific performance criteria of a low vision telescope followed by optical bench testing of a current HLP-VES device adapted with these autofocus components. A preliminary prototype will be constructed for additional headborn laboratory evaluation prior to the phase II production of prescribable prototypes for clinical evaluation. The successful development of such a device may have substantial impact upon the acceptance, adaptation, and utilization of low vision telescopic devices by the visually impaired.

#### **Publications Resulting from This Research**

None reported.

### **[454] Chromatic Factors in Low Vision**

**Kenneth B. Knoblauch, PhD**

New York Association for the Blind, New York, NY 10022

**Sponsor:** *National Eye Institute, National Institutes of Health*

**Purpose**—The proposed work will study the relationship between luminance and chromatic factors in low vision. This will determine under what conditions chromatic contrast can enhance or diminish visual performance.

The long-term objectives are: 1) to develop procedures for evaluating color vision; 2) to provide a better understanding of the interaction of chromatic and luminance contrast in visual performance; 3) to determine if chromatic cues can be successfully utilized to enhance form discrimination and reading; and, 4) to develop tools for predicting what color

contrasts can best be used for the enhancement of visual performance.

**Methodology**—The study will be conducted in three stages: 1) evaluation of residual color discrimination; 2) evaluation of the interaction of luminance and chromatic factors in contrast sensitivity; and, 3) evaluation of the interaction of luminance and chromatic contrast on reading performance. In each stage, age-matched normal observers will be used as a baseline control group.

Our measures will be: 1) a large field saturation

discrimination task; 2) indirect measurement of peak contrast sensitivity and acuity; and, 3) reading performance.

**Publications Resulting from This Research**  
None reported.

### [455] Profile of Visual Function in Low Vision Patients

**David S. Loshin, MD**

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**Sponsor:** *National Eye Institute, National Institutes of Health*

**Purpose**—One of the major problems associated with the management of the low vision patient is the lack of diagnostic tests that accurately reflect the impact of a vision loss. This study will address this problem by investigating the parameters involved in a specific vision task: recognition. Facial recognition is one of the most commonly reported problems for the low vision patient, especially the older low vision patient.

The objective of this research proposal is to develop a battery of clinical tests, the central vision performance profile (CVPP). This profile will provide the clinician with a more accurate description of the functional/performance capabilities of the

older low vision patient. Problems with recognition have been identified as being one of the major frustrations of individuals with visual impairment.

Recognition tasks will be used by the investigators to evaluate performance (or function). The ultimate goal of this project is to gain a better understanding of visual impairment through the development of the vision profile concept, the study of the recognition task, better characterization of residual functional vision, and improve clinical diagnostic services.

**Publications Resulting from This Research**  
None reported.

### [456] Visual Requirements of Everyday Tasks

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**Sponsor:** *National Eye Institute, National Institutes of Health*

**Purpose**—Communication theory will be applied to the study of the visual system to develop a visual sensitivity chart, to measure information capacity, and to extract structure from motion.

**Methodology**—*Develop a visual sensitivity chart which "bypasses" the optics of the eyes.* Thresholds in noise are remarkably insensitive to optical deficits. We will test and further develop a letters-in-noise test chart to assess visual performance in the presence of impaired optics. Theory and pilot data show that performance is almost totally unaffected by optical deficits. This implies that patients with below normal letter-in-noise sensitivity must have neural deficits (either retinal or central). The test chart has the potential for assessing vision even in

the presence of dense cataracts and may have diagnostic value in distinguishing different natural deficits.

*Measure the information capacity of visual attention.* We hypothesize that the information capacity of visual attention can be characterized by how much information capacity is required at the display for optimal performance of an attentive task by the observer. We predict that this information capacity will be constant (on the order of 100 bits) for all visual tasks requiring attention. Twelve experiments will test the hypothesis by measuring the required information capacity for a wide variety of visual tasks.

*Extract structure from motion.* We will investigate motion and depth perception of human and



machine vision systems when images are restricted by low resolution, low contrast, small visual field, or temporal blurring. We will use existing motion algorithms to extract three-dimensional structure from a two-dimensional velocity flow field. Human performance at the same task will be compared to that of the algorithm. The results will test existing

structure-from-motion algorithms as models of motion and depth perception in the human visual system.

#### **Publications Resulting from This Research**

None reported.

### **[457] Sensory Perceptual Deficits in Low Vision**

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**Sponsor:** *National Eye Institute, National Institutes of Health*

**Purpose**—A problem with current clinical visual assessments in patients with low vision is that the information obtained from these assessments often fails to predict difficulties that patients face in performing “real-life” activities.

The general goal of the proposed research is to explore how low-vision patients perform several types of perceptual tasks by examining visual factors which underlie their performance, as well as the performance of individuals who are clinically normal. The information we obtain from these studies can then be used to suggest more innovative clinical assessments which are more directly rooted in real-life activities.

The four parts of this proposal will seek: 1) to clinically define a group of individuals with low vision, as well as a group of age-matched individuals who are clinically normal; 2) to measure spatial contrast sensitivity under different luminance and

target size conditions and the role of spatial frequency sensitivity in object and face perception; 3) to assess the role of visual information in postural stability and locomotion in low vision patients and normal patients; and, 4) to examine how the ability to perceptually integrate visual pattern across space is affected by low vision.

The results obtained in these experiments will be used to suggest more innovative methods for evaluating the visual abilities of low vision patients. In addition, they will be compared to established assessment techniques such as letter acuity, and to contrast sensitivity and quantitative visual field assessment techniques which are recently gaining more popularity.

#### **Publications Resulting from This Research**

None reported.

### **[458] Topology of the Visually-Evoked Potential**

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**Sponsor:** *National Eye Institute, National Institutes of Health*

**Purpose**—The relationship between the scalp topology of the visually-evoked potential (VEP) and the stimulus paradigm that causes it will be studied. This human study relies on a new method that allows noninvasive localization of active cortical areas with a resolution of about 1 cm.

**Methodology**—The method is based on estimating the Laplacian of the VEP field on the scalp by recording second differences of the potential field along orthogonal directions from a multielectrode array. Problems of basic neurophysiological interest will be addressed specific to: 1) cortical localization

of patterned stimuli presented to different parts of the visual field (retinotopic map of the cortex); and, 2) cortical localization of activity subserving visual object recognition.

The retinotopic map will be used to approach several related clinical problems: 1) selection of electrode placements to discriminate foveal signals in the VEP from wide field stimuli as an aid in the evaluation of patients with opaque media, infants, brain-damaged and mentally retarded patients; 2) selection of electrode placements to discriminate

signals from visual field zones 10 to 25 degrees from fixation as an aid to the objective detection and monitoring of field defects in glaucoma; 3) objective measurement of eccentric fixation in amblyopia; and, 4) objective detection of hemianopic and quadrantanopic field defects in neurophthalmological problems.

#### **Publications Resulting from This Research**

None reported.

### **[459] Visual Tests for Patients with Central Scotoma**

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*Sponsor: National Eye Institute, National Institutes of Health*

**Purpose**—The ultimate goal is the development of visual tests that can be used by practicing eye-care specialists to evaluate the “useful” vision in patients with bilateral central scotoma. Patients with central scotomata, as a general rule, have adequate vision for mobility under ideal conditions. The factors that limit their residual vision include contrast and illumination levels.

The specific aims of this investigation are: 1) to determine whether the reductions in contrast sensitivity correlate with the severity of visual problems that patients experience in everyday situations; 2) to determine whether contrast sensitivity correlates better with the patients’ experience than other visual measures, such as the size of the patients’ scotoma; and, 3) to determine whether the measurement of vision at different illumination levels contributes to

the evaluation of the patients’ ability to function in their environment.

**Methodology**—The approach for evaluating the relative merits of different visual tests and illumination levels uses a multiple regression analysis. The patients’ ability to function in “everyday” situations will be assessed by asking the patients to estimate (on a scale of 1 to 10) the degree of visual difficulty that they experience. A multiple regression ( $R^2$ ) value will be computed between the visual measures, such as contrast sensitivity, and the questionnaire responses.

#### **Publications Resulting from This Research**

None reported.



## A. Blindness and Low Vision

### 2. Mobility Aids

#### [460] Motorized and Autofocus Control Systems for Telescopic Low Vision Aids

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Sponsor: VA Rehabilitation Research and Development Service (Project #C557-DA)

**Purpose**—Many visually-impaired individuals use miniature telescopes to provide magnification of near and distant objects. These devices are typically hand-held or mounted in spectacle frames and focus is usually achieved by twisting the outer barrel. Unfortunately, users often encounter problems during use, many of which can be traced to the twisting nature of the focusing operation. The most frequent problems include: loss of the target from the field of view; blurring due to jiggle; and reduced ability of persons with muscular problems, arthritis, or peripheral neuropathy, to manipulate the device. A potential solution to many of these problems is to motorize the focusing process and make it a single-handed operation.

The purpose of this project is to develop and test four telescope systems that incorporate two levels of motorized focus control. The first level involves adding a simple motorized focus control system (motor, drive train, power unit, and controls) to hand-held and spectacle-mounted telescopes. The second level involves modification or development of autofocusing telescope systems. Within this level, we propose to modify an autofocus telephoto camera lens to provide a hand-held telescope with variable magnification and autofocusing capabilities. In addition, we propose to develop an autofocusing spectacle-mounted telescope by adding an autoranging system to a modified version of the simple motorized focus spectacle-mounted system described above.

**Progress**—Three prototype motorized focus telescopes (MFT) of 4, 6, and 8 $\times$  magnification were constructed by adding miniature motors, geared drive trains to effect telescope barrel movement (mechanism of focus), batteries, and a two-push-

button control system to off-the-shelf Keplerian-type hand (manual) focus telescopes (HFT). The MFT's were tested in the lab and also in the field. For the latter, 15 visually-impaired subjects, who were experienced HFT users, completed near and far distance target spotting and identification tasks with a MFT and HFT of the same magnification power. Prior to testing, subjects were given from 15 to 30 minutes of practice with the MFT. Time to complete, and number of identification errors made on each task were recorded, along with subjects' ratings of performance and design features of each device.

**Results**—During lab testing, the MFT's suffered no component breakdowns. Barrel translation speeds in the desired range (8-12 seconds) were achieved, rotation (focus) overshoots were 1.5 degrees or less and resulted in no or minimal perceptible focus change. Gear slip and binding were absent.

No statistically significant differences in the performance measures, average time/target (seconds) and errors/target, were found between the MFT and HFT conditions on either the near or far tasks, despite the short training times with the MFT. Average times spent/target on the near task were 10.98 and 10.18 seconds for the MFT and HFT, respectively. On the far task, these times were 7.79 and 7.84 seconds, respectively. Error rates were low and comparable on both tasks. In contrast to the lack of performance differences, there were significant differences in subjects' preference for a device, with 73 percent selecting the MFT, and 27 percent selecting the HFT. The MFT also received significantly higher ratings than the HFT (sign test  $p < 0.05$ ) for control of focus speed, scene stability while focusing, overall focus control, and overall performance, while device alignment during focus-



ing and user confidence were rated equally. However, weight and size of the MFT prototypes were rated below the HFT.

#### **Publications Resulting from This Research**

None reported.

### **[461] Measuring the Spatial Layout Knowledge of Visually-Impaired Adults**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #C448-RA)*

**Purpose**—The spatial cognition of visually-impaired travelers must be understood if the techniques for training and devices used for orientation are to be optimized. At present, knowledge about spatial cognitive processing is limited even for sighted travelers and generalization from sighted to visually-impaired travelers is not clearly possible. An essential component of this research is determining a valid and reliable measure or measures of the spatial knowledge of the visually-impaired traveler. In the past year, two studies have been conducted in this project.

In the first study, the purposes were to: 1) determine the effects of large versus small scale areas on spatial representations; 2) compare the spatial representations of blind and sighted persons; and, 3) compare three measures of spatial representations of the scenes. There were 30 subjects included in the study: 14 were sighted and 16 were blind.

Three methods of assessing the spatial knowledge were used: 1) absolute distance estimates to ten objects in the space; 2) direction estimates to the ten objects; and, 3) a pushpin map of the ten objects. There were two scenes, one indoor and one outdoor. The outdoor scene was an area of one city block square that surrounded the training center and was used as a mobility training route. The indoor scene was a lounge in the training center used by the clients. Significant differences were found for distance estimates for sighted subjects versus blind subjects; sighted subjects' estimates were more

accurate on the average. Significant differences were found for distance and direction estimates for indoor versus outdoor scenes with these estimates being more accurate indoors.

The purpose of the second study was to study the acquisition of spatial knowledge while the blind person was learning about an unfamiliar environment. Ten subjects who were able to travel independently were asked to walk through a 45- by 45-foot room. The designated path through that room was directed by a set of five commonly heard sounds. Each sound originated at a unique spot in the room: the person walked toward the sound when it started. For five of the subjects, the sounds occurred in the same order for all five trials, so they walked the same route through the room. The other subjects walked a different route on each trial.

In addition to the sounds, there were a number of obstacles that the subjects encountered. During each trial, the subject estimated distances and directions to 10 objects in the room including the five sound sources. They also produced a pushpin map of those objects.

**Preliminary Results**—Preliminary results indicate that subjects who walked the same path for all trials made more accurate distance and direction estimates and pushpin maps.

#### **Publications Resulting from This Research**

None reported.



## **[462] Development of an Objective Measure of Orientation Skill: A Pilot Study**

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University of Illinois, Chicago, IL 60612

**Sponsor:** *VA Rehabilitation Research and Development Service (Pilot Project #C995-PA)*

**Purpose**—This project has two purposes. First, we propose to develop a separate measurement scale of orientation ability with the following characteristics: 1) demonstrated validity and reliability; 2) appropriate for use by orientation and mobility instructors; and, 3) of reasonable generality. Appropriate for use by orientation and mobility instructors means the measure must require less than one hour to administer; be independent of specific settings; and lend itself to reliable, quick, and unbiased scoring. Generality refers to what is measured when we claim to measure orientation skill. We want to measure the overall ability to orient, rather than a specific manifestation of this skill, such as knowing where north is or being able to indicate straight ahead.

Our second purpose is to demonstrate that the measure developed can be used reliably and practically by orientation and mobility instructors. We propose three steps to this project. In the first, we will explore and refine definitions of orientation, translate these into orientation assessment tasks, and pretest those tasks with a few blind subjects. In the second step, we will conduct a formal experimental test of the orientation tasks to determine their usefulness, reliability, and internal factor structure. In the third, we will demonstrate that orientation and mobility instructors can use this orientation test.

### **Publications Resulting from This Research**

None reported.

## **[463] Orientation and Mobility for Blind Adults Over 60 Years of Age**

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**Sponsor:** *Office of Special Education Programs, Department of Education*

**Purpose**—The purposes of this 3-year study are to develop a valid and reliable instrument with which to assess orientation and mobility skills of visually-impaired persons (VIPs) over 60 years of age, and to validate an instructional program in orientation and mobility for use by any group or individual working with this population. Persons who should be able to utilize the final package include any of the various professionals or laypersons in the VIP's formal or informal support systems.

The purpose of the assessment instrument and training curriculum is to provide aged VIPs with the necessary orientation and mobility skills to move around as independently as possible in their immediate living environments. With safer and more efficient travel skills, aged VIPs could optimize use of their environments and lead fuller and more

productive lives. The use of these instructional materials by laypersons and rehabilitation professionals should provide some relief caused by the acute shortage of trained mobility instructors.

The assessment requires the VIP to perform various activities related to five basic domains: sensory, motor, orientation, conceptual, and mobility. Detailed scripting of the assessment situation is provided, along with a breakdown of each step of the activities being scored. Each skill is scored according to how many parts of the total skill are performed correctly, based on explicit descriptions and diagrams.

The training curriculum consists of lessons on the various skills included in the assessment. Complex skills are divided into two or more lessons. Several versions of the curriculum were created to

accommodate the different needs and limitations of VIPs using wheelchairs, support canes, or walkers.

**Progress**—The assessment and curriculum package was used in a field test with 35 aged blind persons. A volunteer or family member was assigned to work with each VIP for the course of the field test. The subjects ranged in age from 61 to 93 ( $M = 73.2$ ), and all were severely visually impaired, with the most frequent diagnosis being light perception. Several types of residential situations were represented.

The field test consisted of a pretest-posttest design, with a treatment program interval. The experimental program condition used the training curriculum, and the control condition used a benign exercise activity.

The assessment and training instruments were revised in response to field test experiences of volunteers, subjects, and project staff. Modifications consisted primarily of improved instructions or scripting, although several skills were reduced or expanded in complexity, and a few new skills were added. The scoring system was reviewed and slightly simplified.

**Future Plans**—The goals of the project during the final year of the project include continued validation and refinement of the materials. A second field test will be conducted, using the revised instruments. The same basic research design from the first field test will be utilized, with pretest and posttest administration of the assessment, and an intervening interval for experimental and control group programs. One major change in the research design for the field test is that trained orientation and mobility professionals will administer the pretest and posttest assessments in order to obtain reliable change scores for validation purposes. Sixty VIPs, and volunteers to work with them, will be recruited in three locations nationwide. Following the field test and revisions, the final instruments and results will be disseminated.

#### **Publications Resulting from This Research**

None reported.

### **[464] Analysis of Navigation Without Sight**

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**Sponsor:** *National Eye Institute, National Institutes of Health*

**Purpose**—The research is concerned with non-visually guided navigation by blind and blindfolded subjects. All experimental tasks involve locomotion through a work area of 30 m by 30 m; some segments of travel will involve guidance by the experimenter while others will involve free locomotion.

The research will also evaluate the utility of a stereophonic auditory display as an interface to a digital map system. The research will add to our understanding of the apprehension of space without vision and will aid in the development of an effective display to be used in conjunction with those digital map/navigation systems which are coming into use and may some day prove useful for the visually impaired.

**Methodology**—The experiments will attempt to analyze navigation performance into two major components: 1) perception of distance and heading changes; and, 2) cognitive representation of surrounding space and transformations of this representation during locomotion.

Precision of the first component will be assessed by simple tasks such as estimation, reproduction, and bisection of distances or angles. The second component will be assessed by more complex tasks, such as having the observer return to the start point after being guided over two legs of a triangle and proceed directly between two locations that are known previously by traveling between each and a common origin.

#### **Publications Resulting from This Research**

None reported.



## [465] Vestibulo-Ocular Reflex in Visual Rehabilitation

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**Sponsor:** *National Eye Institute, National Institutes of Health*

**Purpose**—Magnifying visual aids can occasionally produce dramatic improvements in visual functioning in low-vision patients—those with best-corrected acuity of 20/70 or less. Telescopic and microscopic spectacles can improve both orientation and mobility, and near functioning. Nevertheless, many similarly handicapped low-vision patients cannot tolerate telescopic spectacles or use them effectively. A major cause of this failure may be inadequate vestibulo-ocular reflex (VOR) gain plasticity. In everyday life, head movements continually result from locomotion, heartbeat, muscle tremor, and vibration. The VOR uses head velocity information sensed by the inner ear to move the eyes to compensate for ubiquitous head movements, thus eliminating retinal image slip. Retinal image slip of more than a few degrees per second significantly degrades functional visual acuity. To stabilize images on the retina, VOR gain (eye velocity/head velocity) must be equal to the magnification factor of spectacles worn. Incomplete VOR gain adaptation causes reduced visual acuity, headache, nausea, and ataxia. Preliminary data indicate that visual acuity using telescopic spectacles improves markedly during VOR gain adaptation.

**Methodology**—In this project, a test battery will be developed for prediction of long-term successful function by low-vision patients using telescopic spectacles. The battery will include short-term VOR gain plasticity, visual-vestibular interaction with magnified vision, and dynamic visual acuity and contrast sensitivity during passive head motion with magnified vision. Eye movements will be recorded using DC-coupled electro-oculography.

The test battery will be applied to normal subjects, and then retrospectively to groups of low-vision patients who have succeeded in long-term use of head-mounted magnification devices. A group of new low vision patients will then be prospectively evaluated by a multidisciplinary team consisting of an ophthalmologist, a low-vision optometrist, and mobility specialists. Head-mounted magnification devices will be fitted and supplied as clinically indicated, and long-term follow-up provided. The predictive function will then be validated using data on use of head-mounted magnifiers in daily tasks as the standard of success.

### **Publications Resulting from This Research**

None reported.

## [466] Visual Perception and Orientation/Mobility in Low Vision

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**Sponsor:** *National Eye Institute, National Institutes of Health*

**Purpose**—The long-term objective of our proposed research program is to understand the relationship between orientation/mobility (O/M) performance and the magnitude and type of visual field loss (central versus peripheral). Because perception of the spatial-temporal properties of the environment is essential for successful O/M, we aim to understand the relationship between visual field loss and O/M by investigating visual perception.

Our proposed research program will serve dual objectives: 1) characterize the perceptual anomalies of people with central or peripheral visual field loss; and, 2) understand the relationship between perceptual anomalies and impaired O/M performance. Patients with visual field loss may have difficulty orienting themselves in and moving about novel environments because of a deficit in any of three areas: visual perception of dynamic information,

visual perception of static information, or integration of visual information as related to performance.

**Methodology**—We will address each of these three aspects using two clinical populations with different types of visual field loss, retinitis pigmentosa (RP) and age-related macular degeneration (AMD). For comparison, the same studies will be conducted on normally-sighted subjects.

First, we will use simulations of optic flow patterns produced as an observer moves through an environment and measure postural adjustment to the flow patterns. This measure will index an observer's perceptual response to dynamic visual information.

Secondly, in order to determine whether visual field loss distorts spatial perceptions, we will obtain spatial maps of observers' perceptions of the locations of objects, and from the maps we will compute the perceptual distortions of radial and angular distances.

Finally, we will investigate the integration of spatial-temporal perceptual information as related to mobility performance by measuring both path and velocity patterns of observers in relation to target and obstacle locations.

#### **Publications Resulting from This Research**

None reported.

## **A. Blindness and Low Vision**

### **3. Reading Aids**

#### **[467] A Roller-Bar Modification to Keyboards for Adapted Computers for the Blind: A Pilot Study**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #B986-PA)*

**Purpose**—The purpose of this pilot project is to explore the feasibility of using the Isopoint "roller bar" to facilitate computer access by blind and visually-impaired persons. The roller bar is a special piece of hardware that is added to a standard computer keyboard below and parallel to the space bar. It is designed to emulate the function of a "mouse" cursor controller, which facilitates moving through text-graphic space and making additions, deletions, and changes. The roller bar is operated by the typist's thumbs as both hands remain in home position on the keyboard.

**Methodology**—Hardware used to develop and implement an appropriate user interface is currently under development by the inventor of the device, a collaborator on this project. The inventor has indicated his willingness to lend us working models

of the roller bar for preliminary evaluation. In the meantime, project staff members have been working to specify the computer system, which they will adapt; the software environment, which they will utilize; and the user interface, which they will develop. When completed, this user interface will allow the blind user to communicate his/her editing intentions to the computer for execution. For this activity, the investigators are actively reviewing prior successful instances of computer adaptation for blind and low-vision persons.

**Progress**—Project investigators have identified several salient reasons for focusing initially on the Apple Macintosh computer to support the roller bar: 1) the roller bar emulates a mouse, which is a built-in component of the standard Macintosh interface; 2) the Macintosh computer interface is highly



consistent, allowing techniques learned in one application to be generalized widely to other applications; 3) the Macintosh can be configured to support an EMACS-like editor, extensible via a LISP-like programming language, running in a UNIX-like operating system, thereby providing an extremely powerful and flexible system for developing a working demonstration system; and, 4) blind access to the Macintosh computer is extremely constrained at present, and significant progress made to open up that computer to this population is likely to yield large paybacks. At present, there is a strong trend to make other computer interfaces more Macintosh-like, so results from this project should bring benefits in future years to users of other computer systems as well.

**Results**—To date, project investigators have renewed contact with project collaborators, identified and ordered necessary hardware and software, worked on developing conceptual models for operation of the device, and started to sketch out working

specifications. They are working on the development of software first, while formulating plans to develop a simple roller-bar mock-up, in which a mouse is constrained to behave in the appropriate ways. This decision is based on the desire to work in parallel with the roller-bar's inventor so that when the inventor is able to lend us a working model on a longer-term basis, the investigators will have made major strides in producing the software necessary to make it work.

**Implications**—This pilot project should result in a piece of equipment that will provide proof of concept of the approach, thereby demonstrating that the approach is sensible, the hardware and software are workable, and the results can be beneficial to blind computer users. It will provide an environment for further research into enhancing computer access by blind persons.

#### **Publications Resulting from This Research**

None reported.

## **[468] Relationship of Auditory Skills to the Mobility of Blind Individuals**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #C438-RA)*

**Purpose**—Audition is the major sensory modality available to the blind for detecting aspects of the environment beyond the reach of the limbs or long cane. Auditory training is widely recognized as a major part of mobility training for low vision and blind persons. Mobility training curricula typically include specific practice on auditory skills which have high-face validity, i.e., auditory skills which common sense suggests should be important for mobility. Examples of such skills include: 1) sound identification; 2) sound localization in direction and distance; 3) use of reflected sound for object/obstacle recognition; 4) echo detection to identify openings; and, 5) sound shadow recognition.

There is currently little scientific evidence concerning how and to what extent auditory skills actually contribute to the mobility capabilities of low vision and blind persons. For example, it would

be valuable to know which auditory skills are most useful in mobility, how the contribution of auditory skills to mobility is related to the extent of visual impairment, and if there are important individual differences in the extent to which visually impaired persons use auditory skills in mobility.

The primary goal of the research is to determine how and to what extent auditory skills contribute to the mobility of persons with low vision and blindness. A secondary goal is to determine how the contribution of audition to mobility differs for special populations, who, in addition to having a visual impairment, are elderly, hard of hearing, and/or users of hearing aids.

**Methodology**—We will examine the role of auditory skills in orientation and mobility of visually impaired persons. Mobility performance of the visually



impaired depends on many factors, including sensory, cognitive, motor, motivational, social, historical, and situational. The present research will relate changes in auditory skills as a result of training, to include concomitant changes in mobility performance.

The relationship of auditory skills to mobility performance will be evaluated for six groups of subjects with differences in visual impairment, age, hearing ability, and hearing aid use. Performance on ten auditory skills will be measured before and after mobility training for one-half of each group assigned to a treatment condition, or before and after a comparable waiting period for the remaining half of each group, assigned to a control condition. Multivariate analysis of variance (MANOVA) and multiple, step-wise correlations will be used to determine how and to what extent auditory skills are related to mobility performance.

**Progress**—This phase of the research project concentrated on development of portable test equipment. Testing will be conducted in an acoustically isolated room with an acoustical ceiling, carpeting on the floor, and 4-inch thick Sonex panels which

cover the walls. Ambient noise level and reverberation time for the room will be measured; the Sonex panels will be adjusted to minimize reverberation.

Horizontal localization will be measured with an array of 10 loudspeakers spanning from directly in front of the seated subject (0 degree azimuth) to directly behind (180 degrees) in 20-degree intervals. The distance from the subject to the loudspeakers will be at least 8 feet. The amplitude response of the loudspeakers will be measured in octave bands from 20 Hz to 16 kHz. Loudspeakers will be selected to provide closely matched responses.

Subjects will be tested first with the array on one side of the head, and then on the other side. Sound sources will be presented at each of the 18 angular locations 25 times on a random schedule, for each of two head/body movement conditions, for a total of 900 trials per subject.

**Future Plans**—Based on the current progress, it is anticipated that testing of subjects will begin soon.

#### **Publications Resulting from This Research**

None reported.

### **[469] Evaluation of Electronic Travel Aids (ETAs) for Visually Impaired Individuals**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #406-SA)*

**Purpose**—This study set out to investigate use of electronic travel aids (ETAs) by blind adults. Emphasis included personal and environmental factors that relate to patterns of ETA use. Each of the participants in the study had been trained to use at least one of four ETAs (Laser Cane, Mowat Sensor, Pathsounder, and Sonicguide). Professionals in orientation-and-mobility training for blind persons generally believe that ETAs are used by a small percent who have been trained on the devices.

**Methodology**—During the 24-month study, 284 blind individuals trained to use ETAs were interviewed by telephone. The 1-hour interviews allowed researchers to obtain data on demographic vari-

ables, travel patterns, and perceptions of the benefit of ETAs.

**Results**—Nineteen people were trained on more than one aid. At the time of the interview, 86 percent of respondents reported having an aid at home. Forty-seven percent of the 298 individuals surveyed reported using the device in the last 30 days prior to the interview. Laser Cane and Mowat Sensor use in the last 30 days was reported more than twice as frequent as that of Sonicguide or Pathsounder.

Sixty percent or more users reported rapid, efficient, confident, safer, and less stressful travel at the time of interview as compared to travel before they got their ETA. Ninety percent reported fewer



body and cane contacts. Avoidance of obstacles and detection of distance and direction were situations where the ETA was rated to be of greatest assistance in travel.

The top three responses to perceived benefits of the ETA were object detection, increased independence, and mobility. Fourteen percent of the former users mentioned personal or health reasons for discontinuing use of ETAs. During the 1988 Conference of the Association for Education and Rehabilitation of Blind and Visually Impaired, a survey of Division IX members in attendance was conducted to obtain their estimates of the number of ETA users as a percentage of the number of people who were trained to use ETAs. Results show 70 percent of the professionals responding estimated that less than 25 percent of ETA-trained individuals still use the devices. These estimated use rates are substantially below use rates reported by Mowat Sensor and Laser Cane users, and roughly the same as those for Pathsounder and Sonicguide users.

**Future Plans/Implications**—It may be useful to learn more about users who state they use the ETAs all the time. Where are they using the device? What benefits accrue from ETA use? Is there a difference in reported benefit of these consistent users in comparison to more infrequent users? What is the demographic and personal profile of the everyday user? We do not know who would benefit most from ETAs.

Finally, a follow-up study should be conducted to analyze differences in travel of blind individuals when they use their ETA in combination with their primary aid. It would be useful to understand how environmental variables, such as the complexity of the neighborhood where one lives or travels, affect use of ETAs.

#### **Publications Resulting from This Research**

**Report of a National Survey of Electronic Travel Aids.** Blasch B, Long R, Griffin-Shirley N, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 133-134, 1989.

### **[470] Graphics Environment Integrated Software Package for Blind Users**

**Gregg C. Vanderheiden, PhD; Jon R. Gunderson, MS; David N. Kunz, MS**

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, University of Wisconsin-Madison, Madison, WI 53705

**Sponsor:** *Office of Special Education Programs, Department of Education*

**Purpose**—The graphics display computers which are becoming increasingly dominant in the marketplace pose not only a technical problem, but an ergonomic one: how can non-visual forms of information (tactile and auditory) provide an analog to information displayed in a visual graphic form? In addition, access to this graphic information needs to be provided not just on a rudimentary level but on a level of effectiveness which parallels that of sighted computer users with whom blind individuals interact and compete in education and employment.

**Methodology**—This project entails creating an access system that not only provides adapted output for a blind user, but also specially tailors to the forms in which the information is displayed in the context of specific application software. Microsoft Works (by Microsoft Corporation of Seattle, WA)

was selected as the target application software for three reasons: 1) it runs on the Macintosh computer, a graphics-based computer for which voice-output access is possible; 2) it incorporates three major types of applications (word processing, database, and spreadsheet); and, 3) it is popular enough to be in common use among sighted computer users.

The program will use a modified version of voice-output software developed in conjunction with Berkeley Systems, Inc., along with the haptic tablet interface developed at the Trace Center. Specific features are to be added that accommodate the ways in which commands are issued and information is presented in Microsoft Works. This "tuned access" software package will then be taught to blind users through a specially-designed training program. It is anticipated that the combination of voice-and-tactile access to the operating system, "tuned access" to



specific software, and a training program will bridge the gap between blind users and the graphical interface of the Macintosh.

**Progress**—The basic hardware for Version 1 of this system is completed. Microsoft Works was secured, and is undergoing evaluation with the interface system as it is being developed. In addition, training programs for the system (very critical, due to the lack of blind users experienced with graphics-based systems) are being developed.

**Future Plans**—A prototype of the integrated package with training materials should be complete by the end of 1990. The program will be available for commercial transfer and should serve as a model for other development efforts in the area of access to graphical computer systems for blind users.

#### **Publications Resulting from This Research**

None reported.

### **[471] Effect of Control on Text Presentation**

**Jon R. Gunderson, MS; Gregg C. Vanderheiden, PhD**

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, University of Wisconsin-Madison, Madison, WI 53705

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Many research and development efforts directed toward computer access for blind individuals have concentrated on providing access to standard computers and operating systems. However, relatively few have concentrated on isolating the factors involved in optimizing the interface for the blind user. In order to create the most effective access systems, more needs to be understood about how different variables in text presentation interact in actual situations of use.

Many speech synthesizers and "screen reading" software programs on the market are designed to provide this kind of access. Many of these systems provide control over variables such as speech rate. However, there are questions that remain unanswered regarding which speech rates are useful for different types of tasks.

**Methodology**—Single word comprehension and continuous speech comprehension will be investigated in the context of prose, as well as in software menus, error prompts, and dialog boxes (messages requiring a response). Sentence comprehension is to be studied in text, status messages (which may appear unexpectedly), and prompts. Reading of longer passages is to be analyzed in terms of context (reading unfamiliar text versus editing one's own writing). The research will also investigate the potential for future systems in which audio information is used in

its own optimal form, rather than as an analog to a visual display.

Four experiments have been designed to be carried out this year. Two of the experiments will use standardized tests of speech perception and two will use new tests based on multiple-syllable words. The tests will include the individual words out of context (emulating menu selection), as well as sentences which are semantically meaningful. Two groups of subjects will be used: one without previous exposure to synthesized speech and one that has had experience with it.

**Progress**—A review of current literature and research has been carried out to ensure that studies are soundly designed and unique.

**Implications**—The results of this research will be useful in the future design of speech synthesizers, especially in algorithms for acceleration. They will also have implications in the design of voice-based computer access systems, and will serve to test theories of speech perception and apply them to synthetic speech.

#### **Publications Resulting from This Research**

**Information Processing Model of Human Computer Interaction for People with Blindness and Severe Visual Impairments.** Gunderson J, in *Proceedings of the Planning Workshop on Access to Computers by Blind Individuals*, Madison, WI, 1988.



## [472] State-of-the-Art Planning Workshop on Access to Graphical Operating Systems for Blind Computer Users

**Charles C. Lee, MS; Gregg C. Vanderheiden, PhD**

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, University of Wisconsin-Madison, Madison, WI 53705

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—The greatest single technical obstacle to computer access for blind individuals to arise in the past 5 years is the emergence of computers which use graphical displays as a standard part of their operating systems.

There are a number of researchers and developers who have tackled access problems related to graphical operating systems, as well as many users with a wealth of experience in using the current character-based computer access systems. However, information sharing has occurred primarily only through individual contact and publications.

**Methodology**—A planning workshop was organized in order to ascertain the state-of-the-art on access to graphic operating systems for blind users. This session brought together those with a great deal of knowledge and experience to discuss the problem, to share information, and to determine research and development priorities. The workshop was not to be instructional (i.e., the Trace Center teaching others), but cooperative, with all participants both informing and becoming informed.

The workshop was scheduled to last three and a half days. The four principal objectives were to: 1)

acquaint all of the key individuals in the field with state-of-the-art information and ideas; 2) identify promising access strategies; 3) develop a recommended plan of action for addressing access problems; and, 4) identify and form collaborative links among individuals working in various areas.

**Progress**—The workshop was held in Madison, WI on October 4-7, 1988. Thirty-seven participants were invited, including representatives from computer companies, special access equipment manufacturers, consumers, and researchers.

**Results**—Pre- and post-workshop papers were solicited. The 12 post-workshop papers commissioned are being finalized and compiled into a post-conference summary document. Several cooperative projects are being launched as a result of this workshop.

### **Publications Resulting from This Research**

**Access to Graphical Computers by Blind Users: Results of a Planning Workshop.** Lee CC, Vanderheiden GC, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 21-22, 1989.

## [473] Access to Graphics-Based Operating Systems for Blind Individuals: "Systems 3" Model

**Gregg C. Vanderheiden, PhD; Charles C. Lee, MS; David N. Kunz, MS**

Trace Research and Development Center, Waisman Center on Mental Retardation and Human Development, University of Wisconsin-Madison, Madison, WI 53705

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Graphics-based operating systems pose severe obstacles to computer users with blindness and certain other visual impairments. The first challenge in allowing transparent access to such systems for blind users is to locate operating system "access hooks"—points at which screen information can be accessed in order to be sent to some

alternative output system such as a braille display or speech synthesizer. A second and equally important challenge, however, is to provide a structured interface for the presentation of the screen information so that blind users can interact with the computer in an effective and timely way.

**Methodology**—The first challenge in providing access (outputting screen information) is being addressed as part of a cooperative project with Berkeley Systems, Inc. (BSI). Response to the second challenge (structuring the user interface) is being studied in terms of a "Systems 3" model. This model allows for three different approaches to screen access, which could coexist in eventual commercial implementations.

In System 1, no additional special hardware component is used for navigating the screen. All commands and requests for information are issued using the keyboard. In System 2, a touch tablet is used. The user can touch on "speed lists"—areas of the tablet that correspond to menus and messages—in order to specify what information is to be read back. System 2 does not provide any additional access to the computer, but does provide faster access. Neither System 1 nor System 2 can deal directly with graphics information. In System 3, a "virtual tactile tablet" is added to the system. This tactile tablet allows the user to "feel" the image on the screen by using a mouse-like puck which contains a tactile array (similar to an Optacon).

**Progress**—A prototype tablet for access in System 2 and System 3 modes has been completed, along with driver software. Simulations have been run informally with blind users to obtain initial feedback on the operation of the tablet. Performance is being refined based on this feedback in preparation for formal experimental testing.

**Results**—Now that the basic hardware has been assembled, the much more difficult job of developing the operational software and the system interconnections has begun. This work will be carried out through a cooperative link with Berkeley Systems, Inc. BSI has already done extensive work in this area, with the development of their "OutSpoken" software (similar to the proposed System 1).

#### **Publications Resulting from This Research**

**Nonvisual Alternative Display Techniques for Output from Graphics-Based Computers.** Vanderheiden GC, *J Vis Impairm Blindn* 83(8):383-390, 1989.

### **[474] Textskimmer: A Handheld Reader for the Visually Impaired**

**Nikos D. Asimopoulos**

Topologic Systems Corporation, Blacksburg, VA 24060

**Sponsor:** *National Eye Institute, National Institutes of Health*

**Purpose**—There is a great need for an economical reading machine for use by persons who are blind or visually impaired. A unique device incorporating a handheld scanner and associated character recognition logic allows users to input hard copy to computer files for general use and output through a voice synthesizer or braille output device.

The handheld scanner is robust enough to be used by blind persons. This is made possible by a

high scanning window (1-inch) and a unique patented velocity compensation circuit. The high scanning window also allows for automatic format analysis. Other patented techniques incorporated in this device enable the reading of very poor quality text and is inherently font-insensitive.

#### **Publications Resulting from This Research**

**None reported.**



## [475] Electronic Braille Page Output Device Using Nitinol

**David A. Johnson, PhD**

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*Sponsor: National Eye Institute, National Institutes of Health*

**Purpose**—We propose to provide for nonsighted persons the convenience of tactile access to the same kind of information that is available via the visual computer monitor. A page format of refreshable Braille characters will enable a visually-disabled person to participate effectively in word processing, computer programming, and related tasks. This device will augment existing aids such as Braille printers, speech synthesis, and single-line Braille character output systems by providing tactile output in which content is related to format.

**Progress**—In Phase I, a single Braille character was built and tested. The characters are represented by

movable pins. Each pin motion is actuated by a wire of Nitinol shape-memory alloy which is heated by electric current. This mechanism takes little space, provides adequate force, requires modest power, and is inexpensive to manufacture.

**Future Plans**—Phase II research will be aimed at construction and evaluation of a prototype containing 20 rows of characters with emphasis on defining user requirements and manufacturing costs.

### **Publications Resulting from This Research**

None reported.

## [476] Psychophysics of Reading: Normal and Low Vision

**Gordon E. Legge, PhD**

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*Sponsor: National Eye Institute, National Institutes of Health*

**Purpose**—We will measure how reading by observers with normal and low vision depends on the stimulus properties of text. The stimulus properties of text that are necessary for normal observers to read are defined to be the visual requirements of reading. Our research has three primary goals: 1) to measure the visual requirements of reading under conditions that are relevant to low vision; 2) to develop simple tests of visual capacity that can predict reading performance of low-vision observers; and, 3) to discover the influence on reading performance of stimulus properties, ophthalmic disorder, acuity deficit, and field loss for low-vision observers. We will use psychophysical methods in a series of five experiments.

First, we will discover the visual requirements of normal reading with special emphasis on contrast and spatial frequency. We will also measure the visual requirements of letter, word, and picture

recognition. Second, we will seek to develop improved means for measuring contrast sensitivity, based on recognition rather than detection, to quantify the visual capacities of low-vision observers. Third, we will determine whether recognition tests of contrast sensitivity and knowledge of the visual requirements of normal reading can be used together to predict reading performance of low-vision observers. Fourth, we will measure effects of several special factors of low-vision reading—glare, contrast reversal, wavelength, and defocus. Finally, we will test hypotheses that attempt to explain psychophysical properties of reading in terms of known properties of pattern vision.

**Implications**—The research will be useful in three ways: 1) improved understanding of the sensory constraints of normal reading; 2) developing systematic techniques for testing low-vision capacity with

the aim of specifying image properties required of an appropriate reading aid; and, 3) establishing necessary stimulus characteristics for new low-vision reading aids.

#### **Publications Resulting from This Research**

None reported.

### **[477] Studies of Low Vision Reading and Face Recognition**

**Gary S. Rubin, PhD**

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**Sponsor:** *National Eye Institute, National Institutes of Health*

**Purpose**—Low-vision subjects with central field loss read much more slowly than would be expected on the basis of standard clinical measures of visual function (e.g., visual acuity and contrast sensitivity). The principal goal of the proposed research program is to determine what limits reading performance in this group of subjects and to explore new techniques of image enhancement to circumvent the visual limitations on reading in the absence of central vision. We will study reading performance in young and elderly normal observers and in low-vision subjects with central scotomas due to macular disease, primarily age-related maculopathy.

**Methodology**—To determine the limitations on reading of normal peripheral vision, normal observers will read text in the presence of an artificial scotoma stabilized on the retina with a dual-Purkinje eye tracker. Because inappropriate eye movement may severely limit peripheral reading, we will also study reading performance by presenting the text one word at a time in a fixed retinal location. This technique, rapid serial visual presentation (RSVP), virtually eliminates the need for saccadic eye movements.

We will determine the extent to which the peripheral retina of low vision subjects behaves like normal peripheral retina. We will measure spatial phase or position sensitivity using phase discrimination and vernier tasks. Lateral masking ("crowding") effects will be investigated by measur-

ing letter recognition in the presence or absence of flanking patterns, and metacontrast masking (backwards and forwards masking in the temporal domain) will be measured with a word recognition paradigm.

Spatial undersampling will be investigated by comparing detection and orientation discrimination of grating patches, and temporal undersampling will be evaluated by comparing critical flicker frequency (CFF) with two-pulse discrimination. In each case we will then compare performance of low-vision subjects with central scotomas to that of normal subjects using eye-tracker controlled peripheral viewing.

We will determine the relation of low-vision reading ability to the size, location, density of central scotomas, and any discovered abnormalities of peripheral visual function. Given a better understanding of the visual limitations on peripheral reading performance, we will investigate new techniques for enhancing or modifying the image in order to improve performance.

We will explore nonlinear magnification and increased letter spacing to overcome crowding problems, low-pass spatial and temporal filtering to reduce lateral and metacontrast masking, and the use of static and dynamic texture to improve letter segregation.

#### **Publications Resulting from This Research**

None reported.



## [478] Low Vision Reading: Optimizing Visuo-Motor Performance

**George T. Timberlake, PhD**

Eye Research Institute of the Retina Foundation, Boston, MA 02114

*Sponsor: National Eye Institute, National Institutes of Health*

**Purpose**—A significant obstacle to the independence and rehabilitation of the visually handicapped is a loss of their ability to read text. Despite this, little is known about the retinal loci and retinal movements used in reading by our increasing population of elderly patients with macular disease. Scanning laser ophthalmoscopy provides a unique means of obtaining this data because it permits determination of the retinal loci of visual defects, measurement of visual acuity profiles on the retina, and direct observation of retinal movements during reading.

We propose to use scanning laser ophthalmoscopy to obtain this information in a study that will: 1) determine optimal retinal loci and move-

ments for individuals with macular disease; 2) analyze which combinations of text orientation, size, and movement are most effective for particular scotomata size and locations; and, 3) investigate procedures for training patients to optimize residual retinal function.

Additional long-term benefits from this study include the development of more efficient low-vision aids and more effective text displays for the visually impaired.

### **Publications Resulting from This Research**

None reported.

## [479] Special Education Shows Its Stripes: Bar Code Technology

**Alan G. Van Biervliet**

Learning Express, Little Rock, AR 72204

*Sponsor: National Institute of Child Health and Human Development, National Institutes of Health*

**Purpose**—The purpose of this project is to translate the research findings concerning the demonstrated educational uses of bar code technology into validated curriculum materials and strategies for children with learning disabilities, mental retardation, visual impairments, and communication impairments. Bar code technology uses portable bar code readers consisting of handheld scanners, microprocessors, and speech synthesizers to provide auditory information, feedback, or instructions. The bar codes used by these devices are printed software which contain digital instructions for producing sounds, words or phrases, information concerning

the accuracy of a response, or other instructions for the microprocessor.

The proposed project will further develop and evaluate bar-coded materials and instructional strategies for improving reading skills, teaching sight words, and teaching braille to children with a wide range of disabilities, as well as develop a microcomputer-based software package for creating and printing bar codes in English and Spanish.

### **Publications Resulting from This Research**

None reported.

## [480] Reading and Saccade Control Limits with Maculopathy

**Stephen G. Whittaker, PhD**

Pennsylvania College of Optometry, Philadelphia, PA 19141

*Sponsor: National Eye Institute, National Institutes of Health*

**Purpose**—When macular disease impairs central vision, reading rate can deteriorate significantly even when print size is magnified to compensate for loss in visual acuity. Prior research implicates the presence of central scotoma as the aspect of visual function that most reliably limits reading rates. Little is known, however, about the relationship between scotomata, eye movements, and reading performance. Using recently-developed systems for objectively measuring eye movements and precisely defining central scotoma, the proposed research will identify limits imposed on saccade control and reading rate by various scotoma characteristics such as size and density. The most reliable predictor of existing performance on a visual task is a direct measure. Accordingly, we will adapt existing instruments for reliably and rapidly assessing low vision reading rate for the clinic and research. Performance limits, however, cannot be directly measured. Limits are important to predict so that individualized rehabilitation programs can be designed to

circumvent the most limiting facet of a vision loss. This research will define the limits various scotoma characteristics impose on reading rate, saccade frequency required for visual scanning, and fixation duration.

**Methodology**—Scotoma size, residual central function, and form factors will be correlated with reading rate and saccade control variables by comparing the performance of trained individuals with either aging related or juvenile maculopathies. These subjects will have demonstrated asymptotic performance. Finally, measures of eye movements will be combined with measured scotoma characteristics and a multiple regression analysis will be used to determine the most reliable predictor of an individual's performance limits and the least limiting visual scanning strategy.

### **Publications Resulting from This Research**

None reported.

## [481] Microcomputer Software for Blind and Partially-Sighted People

**Michael J. Tobin; Malcolm Ross; Simon Spencer**

Research Centre for the Education of the Visually Handicapped, University of Birmingham, Birmingham B15 2TT England

*Sponsor: Research Centre for the Visually Handicapped*

**Purpose**—The microcomputer software aspect of the Centre's work is concerned with development of low cost programs designed to enable visually-handicapped people (from pre-schoolers to adults in work) to have access to the same information and facilities as their fully-sighted peers.

**Progress**—There is now a suite of over 40 programs. For very young and the less intellectually able children, the materials developed or under development are aimed at the enhancement of various basic perceptual and cognitive skills. Control is being

effected by means of the conventional keyboard, touch-sensitive screens, joysticks, concept keyboards, and similar devices. For older students and adults, the software (for teaching mathematics and for word-processing purposes) allows for output in the form of large print, braille, and synthetic speech; several programs also provide large character or synthetic speech output from teletext systems.

One particularly interesting new set of software allows for "Viewbooks" to be used by partially-sighted students (*Magnified Viewbooks*) and by totally blind learners (*Talking Viewbooks*). View-



books, a commercial product, are books published on disc rather than on paper, each page being presented as a "screenful" of information, together with Viewbook commands. These commands help to locate any page, word, or phrase, permit the user to edit or annotate texts that are being studied, and arrange for sections to be produced as hard copy. The texts include classics from English literature, and standard works in Media Studies, Sociology, Geography, Economics, Social Policy, History, and General Studies.

Although the software was originally designed for implementation on the BBC range of microcomputers, much of it is now being rewritten to run on IBM-compatible devices.

**Future Plans**—With the advice of teachers and rehabilitation professionals, the Centre is proposing to extend the range of this low cost software so that the educational and vocational needs of visually-

handicapped people can be met. In addition, more time and resources will be devoted to increasing the range of microcomputers on which the materials can be run.

### Publications Resulting from This Research

**Electronic Publishing and Visually Handicapped Learners.** Hawley A, Jefferys S, Ross M, Spencer S, Tobin MJ, *The New Beacon*, LXXI(844):253-255, 1987.

**Centre Computer Base for Visually Handicapped Children, Students, and Adults.** Spencer S, Ross M, Tobin MJ, Blenkhorn P, *Br J Visual Impairm* V(2):67-69, 1987.

**Visual Stimulation Using Microcomputers.** Spencer S, Ross M, *Eur J Spec Needs Educ* 3(3):173-176, 1988.

**Closing the Gap. Facilitating Integration: Microcomputer Technology and the Visually Handicapped Learner.** Spencer S, Ross M, *Spec Child* 28:20-21, 1989.

**Assessing Functional Vision Using Microcomputers.** Spencer S, Ross M, *Br J Spec Educ* (Research Supplement) 16(2):68-70, 1989.

**Software Packages for the Young Visually Handicapped.** Spencer S, Ross M, *Spec Child* 31:20-21, 1989.

## B. Deafness and Hearing Impairment

### [482] Validity and Reliability of a Physiological Test of Vestibular Function

**Richard H. Wilson, PhD; Dennis P. O'Leary, PhD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C412-RA)

**Purpose**—Balance and movement disorders associated with the inner ear are common medical complaints affecting approximately 40 percent of the population over 40 years of age. There is a need for a well-documented vestibular test that is comfortable to the patient, simple to implement, tests horizontal and vertical vestibulo-ocular reflexes, provides useful diagnostic results, and is relatively inexpensive and fast to administer.

A computer-based technique has recently been developed by the co-principal investigator, Dr. Dennis O'Leary, to fulfill these needs. The technique, which is called the Vestibular Autorotation Test (VAT), monitors the horizontal and vertical vestibulo-ocular reflexes (VOR) in the 2-6 Hz physiological range using 18 seconds of horizontal or

vertical movement with the eyes fixed on a stationary target. Eye position and head velocity information (calculated from eye position information using a 2-point central difference deviate algorithm) and head velocity data are reduced to 100 samples/s from which VOR gain (eye velocity amplitude/head velocity amplitude) and phase are computed by discrete Fourier analysis, using signal processing techniques on a personal computer.

For the VAT to be developed as a routine clinical procedure, which potentially could replace current electronystagmography (ENG) techniques including the caloric, tracking, and rotatory chair procedures, a broad normal database including all age groups is needed to establish the validity and reliability of the VAT. The following questions are



being addressed in the three-year study: 1) Does the VAT provide a valid and reliable assessment of vestibular function? 2) Are the data provided by the VAT more sensitive to vestibular dysfunction than are the data provided by the currently used ENG techniques? 3) Is there a parallel age-related decline in vestibular and auditory function that can be measured with the VAT and with traditional auditory tests? and, 4) Does the VAT provide sensitive data for monitoring vestibular function of patients receiving potentially vestibulotoxic medications?

**Progress**—We are currently evaluating only subjects with normal ENG results, normal hearing sensitivity for their age, and no vestibular complaints. Comparisons will be made among the results of the VAT,

ENG, and audiological tests. Ninety-three subjects have been evaluated with the VAT as of this date and the results are reliable across subjects.

**Future Plans/Implications**—From these data, the range of normal variability will be established. These norms will be used as a basis of comparison for abnormal subjects. One potential long-range application of the VAT device is to use a miniaturized version to monitor changes in vestibular function during postural rehabilitation procedures with patients who are dizzy or who have unsteady gaits.

#### **Publications Resulting from This Research**

None reported.

### **[483] Computerized Adaptive Methods for Selecting Hearing Aids**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #C432-RA)*

**Purpose**—The general purpose of this project is to explore critical variables which govern the choice of frequency-gain characteristics preferred by individuals with hearing impairment, and to investigate the potential use of adaptive test strategies as a method for determining the preferred frequency gain characteristics within the hearing-aid selection process. Variations of the simplex adaptive test strategy incorporating a paired comparison technique is the basic method utilized to accomplish these goals. The experimental protocol is implemented via a master hearing aid which incorporates computer-controlled digital filters so that precise and rapid real-time changes in the hearing-aid characteristics can be achieved.

Another important feature of these investigations is the use of a probe-microphone system for determining the actual frequency-gain characteristics and insertion gain provided by the hearing-aid/earmold system. The probe measurement incorporates an acoustic technique that estimates the location of the probe in the ear canal relative to the eardrum. As a consequence, it is possible to conduct these measurements with the probe located at a

distance of 4 to 6 mm from the ear drum of each subject, thus avoiding the usual problems which occur when probe location in the canal is unknown.

**Progress**—The specific goals during the current year were to: 1) assemble the experimental equipment; 2) develop the software programs necessary to conduct the adaptive procedures; and, 3) conduct an initial experiment to compare the preferred frequency-gain characteristics obtained from two- versus three-dimensional simplex adaptive strategies.

Following completion of the required software developments, the instrumentation was assembled to conduct an investigation to make comparisons between the frequency-gain characteristics obtained with a two-dimensional simplex strategy and those chosen with a three-dimensional strategy. For the two-dimensional simplex, the frequency spectrum is divided into two parts (a low-to-mild frequency band including frequencies below 1,000 Hz and a mild-to-high frequency band from 1,000 to 5,000 Hz). The bands for the three-dimensional simplex contain three separate bands (a low band extending



from 200-600 Hz, a mid-band from 600-2,000 Hz, and a high band from 2,000-5,000 Hz).

The impetus for this study is recent experimental observations suggesting that the adaptive strategy produces results similar to those obtained with several prescriptive frequency-gain prediction techniques, but is not necessarily superior to those other methods. It was reasoned that the adaptive procedure, because it does not necessitate fixed relations among auditory characteristics of hearing loss, would in fact have led to optimal results consistently. Earlier investigations with adaptive procedures incorporated only changes in two dimensions, that is, only a low and a high frequency band were varied. Individuals with hearing loss, especially those with marked variations in audiometric configuration (e.g., steeply sloping high frequency hearing loss), may however, require more flexibility in the frequency response pattern than can be achieved by dividing the spectrum into only two frequency bands.

Ten hearing-impaired subjects were used as subjects in the experiment. Five subjects had flat or mildly sloping audiometric configurations and the remaining 5 subjects had steeply sloping hearing loss. Each subject estimated the preferred frequency-gain characteristic for each simplex adaptive

procedure during two sessions. The subjects listened to continuous discourse; generalized instructions were given suggesting that the subject make the preference decisions based on several attributes of quality and intelligibility.

**Results**—The results showed that subjects generally made similar preference judgments for both the two- and three-dimensional simplex strategies. Interestingly, the preferred frequency-gain characteristics for the group resulted in insertion gains similar to those recommended by the National Acoustic Lab (NAL) prescriptive procedure. The results also indicated that individuals with steeply sloping high frequency loss consistently preferred more gain in the mid-frequency region, available within the three-dimensional strategy, than comparable gains chosen with the two-dimensional strategy.

**Future Plans**—We plan to continue evaluation of the adaptive procedures in a larger group of hearing-impaired subjects to determine whether the preferred frequency-gain characteristics varies with signal-input level.

#### **Publications Resulting from This Research**

None reported.

## **[484] An Auditory Prosthesis for Sensorineural Hearing Loss**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C054-3RA)

**Purpose**—The object of this research is to determine the optimal design parameters and fitting procedures for a new multichannel compression hearing aid for patients with sensorineural hearing loss (SNHL). Previously, we have demonstrated that an initial 8-channel version of the aid was very effective in helping individuals with SNHL to recognize speech sounds in the presence of noise—a key problem for SNHL patients. The present work will include a systematic study of the following parameters of the multichannel compression hearing aid: 1) number of channels; 2) time-constant of the compression; 3) location of the channel boundaries with respect to the configuration of the hearing loss; 4) type of

compression system; and, 5) shape of the compression function. The present work will also examine the importance of learning to use a multichannel compression hearing aid. Aspects of the previous results suggested that the performance of the subjects with the new aid had continued to improve throughout the study, with over 40 hours of testing per subject.

**Progress**—The performance of the multichannel compression aid improves as the number of channels increases, up to 8 channels, and then the performance is essentially constant from 8 to 16 channels. The experiments concerning the time-constant pa-



parameter also are completed, but the detailed data analysis remains to be done: constant time windows, the same in all channels, from 5 msec to 200 msec were used. In a second experiment, time windows varying inversely with frequency were compared with the 10 msec constant time window. Performance was measured in 15 SNHL subjects at 5 signal-to-noise ratios (S/N) with both a male and a female voice. At this time, we have begun to measure the effect of the location of the bands with respect to the individual hearing loss configurations.

**Preliminary Results**—The performance of our multichannel compression system proved to be quite insensitive to the time parameter. Only one-third of the subjects showed statistically significant differ-

ences among the six constant time windows (5, 10, 20, 50, 100, and 200 msec) and only two subjects showed statistically significant differences between the constant time window and time windows varying with frequency. It is encouraging that our multichannel compression system works as well with short- as with long-time windows, because both the construction cost and the physical size of a hearing aid incorporating such a system would increase with the duration of the required time window.

#### Publications Resulting from This Research

**Speech Discrimination with an 8-Channel Compression Hearing Aid and Conventional Aids in a Background of Speech-Band Noise.** Yund EW, Simon HJ, Efron R, *J Rehabil Res Dev* 24:(4)161-180, 1987.

### [485] Variables Affecting Hearing Aid Performance

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C337-RA)

**Purpose**—The goal of this program is to complete electroacoustic and behavioral studies of the interaction of acoustic sound sources with the acoustic impedance of the ear canal and the middle ear. For these purposes, a personal computer-based measurement system (IBM-PC XT/AT) has been developed and is being refined.

**Progress**—The measurement system has been configured to make measurements of the magnitude and phase transfer function of insert transducers sealed in the ear canal. The current system has been completed and is based on data acquisition performed by a Fast Fourier Transform (FFT) spectrum analyzer (Rapid Systems, Inc., Model R1200) which is controlled by a personal computer (IBM/AT-compatible). The transfer function data are used by locally-developed software to compute the real and imaginary parts of acoustic input admittance or impedance. The system employs a miniature loudspeaker and a probe microphone which terminates in an assembly suited for coupling to the ear canal. A pseudo-random noise drives the earphone. A distributed parameter model for estimating the acoustic immittance of the ear canal has

been implemented. The algorithm calls for the residual ear canal to be treated as  $n$  number of slices. Each slice has a measured cross-sectional area and a measured thickness; then the cascade parameters are computed for each, and, by matrix multiplication, all of the cascade parameters are combined into one  $2 \times 2$  matrix of the total cascade parameters of the ear canal. Finally, eardrum impedance or admittance values are computed.

Additional routines have been completed which are used to calculate the acoustic impedance of insert transducers and work is underway to automate psychoacoustic experiments using the personal computer.

**Results**—Measurements of the acoustic impedance of the transducer used as the sound source in this program have been completed. Estimates of impedance quantities in the frequency range from 160 to 4,800 Hz from the ears of normal subjects have been acquired. In this phase of the study, the ear canal was treated as a tube with two equal "slices." The dimensions of the ear canal were acquired by estimating the volume of the ear canal and obtaining the diameter of the canal using a graduated set of



inserts. These estimates were used to calculate the cross-sectional area and thickness of the slices.

Measurements were made on 6 subjects on two different days. Good test-retest agreement was obtained for the real and the imaginary parts for both the input and eardrum locations. Additional data have been collected to study individual differences. In addition, data obtained on 7 normal ears are in close agreement with published data.

Studies have also been completed on the effects of earmold canal length and earmold venting. Estimates of ear canal sound pressure levels (SPL) and auditory threshold were obtained from 20 subjects. Small but statistically significant differences in SPL were observed between vent-length conditions, but these were not reflected in the threshold data. In addition, the threshold measures underestimated the effect of venting in the low frequencies by about 7 dB. Additional studies of these effects are underway.

**Future Plans**—Data collection on ears with conductive and sensorineural pathology using the impedance measurement system are planned. Work toward developing a viable technique to estimate the

impedance of the residual ear canal will continue. Additional behavioral studies are planned and in progress.

### Publications Resulting from This Research

- Ear Canal SPL as a Function of Residual Volume.** Cooper W, Larson V, Balfour T, Copps T, Brooks B, *ASHA* 30(10):175, 1988.
- Experimental Determination of Cascade Parameters of a Hearing-Aid Microphone Via the Two-Load Method.** Egolf D, Haley B, Bauer K, Howell H, Larson V, *J Acoust Soc Am* 83:2439-2446, 1988.
- Low-Frequency Thresholds Produced by Insert Earphones.** Larson V, Cooper W, Ahlstrom C, DeChicchis A, *ASHA* 30(10):147, 1988.
- Reference Threshold Sound Pressure Levels for the TDH-50 and ER-3A Earphones.** Larson V, Cooper W, Talbott R, Schwartz D, Ahlstrom C, DeChicchis A, *J Acoust Soc Am* 84:46-51, 1988.
- A Technique for Simulating the Amplifier-to-Eardrum Transfer Function of an In Situ Hearing Aid.** Egolf D, Haley B, Howell H, Larson V, *J Acoust Soc Am* 84:1-10, 1988.
- Ear Canal SPL Relationships to Residual Volume and Venting.** Cooper W, Copps T, Larson V, Balfour P, *ASHA* 31(10):117, 1989.
- Estimates of Aural Acoustic Impedance Quantities.** Larson V, Egolf D, Cooper W, Oliver J, *ASHA* 31(10):123, 1989.
- A Comparison of Three HA-1 Couplers.** Larson V, Cooper W, *Ear Hear* (in press).

## [486] Direct Measurement of Loudness Recruitment in Hearing-Impaired Veterans

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C296-2RA)

**Purpose**—This project is primarily concerned with the feasibility of using direct magnitude-scaling procedures for the measurement of loudness in bilateral sensorineural impairment. To accomplish this goal, the relations among sensation-magnitude functions in normal and sensorineural-impaired hearing are under investigation.

**Methodology**—Most of the loudness measurements were obtained by absolute magnitude estimation (AME), absolute magnitude production (AMP), and cross-modality matching (CMM). The measurements involved two sensory continua: perceived length and loudness. From these procedures, four sensation-magnitude functions were generated for each partic-

ipant. Some measurements were also obtained with the conventional procedure of loudness balance. The stimuli were tone bursts that varied in frequency from 500 to 4,000 Hz and lines of light displayed from 35-mm slides. All the measurements were obtained in a soundproof booth. Listening was monaural through a TDH-49 earphone mounted in an MX-41/AR cushion.

**Progress**—The slope of the loudness function was obtained for individuals and groups. Distributions of the slope were determined from AME and AMP of loudness and from CMM and AME of perceived length. The former procedure gives the directly measured value of the slope and the latter procedure



gives the predicted value. An evaluation of the two distributions shows just how closely the measured and predicted slopes for loudness agree.

To date, loudness measurements were obtained at a frequency in the region of impaired hearing for 107 people with sensorineural hearing impairment. The results for 100 people, 78 with noise-induced losses, have been completely analyzed. From the total group of 107 people, pure tone loudness measurements were also obtained for 36 people in the region of normal hearing. In addition, 12 people performed interfrequency loudness matches. Data analysis is continuing.

**Preliminary Results**—Individual slopes obtained from AME and AMP of loudness for 100 hearing-impaired people range from 0.76 to 5.91 with a mean of 1.98; the ones derived from CMM and AME of perceived length for the same people range from 0.86 to 6.19 with a mean of 1.95. More than half of the measured deviations are less than 20 percent with an overall average of -1.5 percent. Also, the individual values of the measured and predicted slopes are significantly correlated ( $r=0.70$ ,  $p<0.01$ ). Taken together, these results show that transitivity is preserved for hearing-impaired individuals.

A comparison between the results obtained for a control population of 51 people with normal hearing, and the 100 people with impaired hearing, produced three main findings: 1) for hearing losses greater than 40 dB, the values of the individual and mean slopes are typically larger than those obtained in normal hearing; 2) the standard deviation of the mean is larger for the hearing-impaired listeners than for those with normal hearing; and, 3) for both the normal and impaired groups the standard deviation is larger for measured than for predicted slope distributions. Furthermore, the results unexpectedly show that, for groups of people with approximately homogeneous thresholds and a common underlying etiology, the standard deviation is a nearly constant proportion of the mean, giving a

coefficient of variation of about 27 percent in normal and impaired hearing. Thus, consistent with loudness matching, the size of the slopes depends directly on the degree of hearing loss. This relation holds for group and individual data.

**Future Plans/Implications**—The results thus far suggest that CMM offers much promise for the measurement of individual loudness functions. Loudness and annoyance measurements are planned with a larger and more diverse population of people with sensorineural impairment. To verify the results obtained by magnitude scaling, additional loudness matches are needed.

#### Publications Resulting from This Research

- Loudness Functions in Noise-Induced and Noise-Simulated Hearing Losses.** Hellman R, in *Proceedings of the 5th International Congress on Noise as a Public Health Problem*, Stockholm, Sweden, 2:105-110, 1988.
- Measurement of Loudness in Bilateral Sensorineural Impairment.** Hellman R, Meiselman C, *Annual Meeting of the American Speech-Language-Hearing Association*, Boston, MA, 133, 1988.
- Non-Linear Extension of the McGill-Goldberg Counting Model.** Hellman W, Hellman R, *Proceedings of the International Neural Network Society*, Boston, MA, 1:296, 1988.
- Prediction of Individual Loudness Exponents from Cross-Modality Matching.** Hellman R, Meiselman C, *J Speech Hear Res* 31:605-615, 1988.
- Derivation of Neural-Count Functions from Psychophysical Measurements of Intensity Discrimination and Loudness.** Hellman R, Hellman W, *Assoc Res Otolaryngol* 12:302, 1989.
- Is Stevens's Power Law Valid?** Hellman R, *Behav Brain Sci* 12:276, 1989.
- Relations Between Neural-Count and Intensity-JND Functions for Single Auditory-Nerve Fibers.** Hellman W, Hellman R, *J Acoust Soc Am* 85:S35, 1989.
- The Slope of the Loudness Function for Individuals and Groups with Normal and Impaired Hearing.** Hellman R, Meiselman C, *J Acoust Soc Am* 85:S108, 1989.
- Intensity Discrimination as the Driving Force for Loudness. Application to Pure Tones in Quiet.** Hellman W, Hellman R, *J Acoust Soc Am* (in press).
- Loudness Measurement by Magnitude Scaling: Implications for Intensity Coding.** Hellman R, in *Ratio Scaling of Psychological Magnitudes—A Tribute to the Memory of S.S. Stevens*, G.A. Gescheider, S.J. Bolanowski (Eds.), New Jersey: Earlbaum Associates, Inc. (in press).
- Loudness of Two-Tone-Noise Complexes.** Hellman R, Zwicker E. Invited paper, *Proceedings of Inter-Noise 89* (in press).



## [487] Perception of Reverberation by the Hearing Impaired

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**Purpose**—The effect of a reverberant room is to act as an acoustical filter, the frequency response of which is typified by numerous ripples. In turn, the spectra of sounds occurring within such rooms have this rippled frequency response imposed upon them, so that their spectra are marked by peaks and troughs. In spite of these obvious acoustical characteristics of the reverberant microstructure, it is noteworthy that very little attention has been paid to their perceptibility, or to their effect upon speech intelligibility. This project is addressing these issues.

**Progress**—Several experiments are underway, involving normal hearing and hearing-impaired subjects: 1) ripple detection studies involve the perceptibility of spectral ripples using 1-sec noise bursts including spectral peaks or notches up to 12 dB that are one-half the width of the critical band (CB) which must be discriminated from flat spectra; 2) reverberation detection involves the use of noise bursts and speech recorded in a reverberant room (approximately 0.4 sec) in various combinations of locations (proximity to and orientation with respect to the walls), and distances between the source and microphone; 3) spectral smoothing experiments include the use of digital filtering paradigms to smooth the ripple in the reverberant spectra. These use a range of filter conditions from 1/3 CB to 11 CBs, respectively addressing rapid, within-CB and long period across-CB ripples; and, 4) speech recognition and confusion experiments use a modification of the City University of New York Nonsense Syllable Test (CUNY NST) developed and standardized for use in this project.

Speech (nonsense syllables) processed under the various combinations of locations and source-microphone locations described above, is presented to subjects in a closed-set allowing all consonant confusions.

**Results**—Subjects with normal hearing are able to detect the presence of spectral peaks. The difference limen for spectral peaks approximates 3 dB. In

contrast, spectral notches cannot be detected even with depths as great as 12 dB. Moreover, it appears that the effects of spectrum smoothing is not detectable for smoothing filters which are less than one critical band in width. These findings appear to support the hypothesis that spectrum ripple between critical bands is more perceptible than is spectral ripple occurring within critical bands.

Development of a modified CUNY NST has been completed. This approach involves the presentation of the test syllables in isolation (extracted from their original carriers) and the availability of virtually all consonants as response alternatives. As expected, performance-intensity functions (20 to 52 dB SPL) for these materials presented in quiet and noise (+5 dB S/N) were somewhat less shallow than those associated with the original paradigm. It is interesting to note that initial error analyses have suggested that more initial than final position confusions are yielded by this approach, which is consistent with data obtained by Wang and Bilger (1973) using a similar paradigm. The development of this test instrument enables the consonant confusion studies.

**Future Plans**—Data is in the process of being collected for the experiments dealing with the effects of spectrum smoothing on the perceptibility of reverberation, and on the effects of differing reverberant microstructures upon consonant confusions, for normal hearing subjects and those with hearing impairments. Following this, we plan to determine if spectrum-smoothing paradigms result in perceptible changes in reverberant speech quality and in the measured intelligibility of reverberant speech. Programming is underway to generate computer-simulated reverberant microstructures in order to more precisely categorize conditions to study the perceptibility of reverberant ripple and of procedures to smooth the spectral ripple.

### Publications Resulting from This Research

None reported.



### [488] Prospective Randomized Cooperative Study of Advanced Cochlear Implants

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**Sponsor:** VA Rehabilitation Research and Development Service (Cooperative Study #304)

**Purpose**—This study, initiated in January, 1987, is a multi-center trial involving seven regional VA Medical Centers and was designed to compare the efficacy and safety of the 3M/Vienna® single-channel and three multichannel cochlear implant devices: Nucleus®, Symbion Ineraid®, and UCSF Storz devices.

**Methodology**—The study originally was to include a total of 120 patients accrued from seven participating VA Centers over a period of three years. An additional two years of patient follow-up to determine long-term efficacy is planned for all study patients. Delays in development of the UCSF device have necessitated a change in the study plan. Only three devices were to be studied in 90 patients. In November 1988, the 3M Company withdrew the 3M/Vienna® single-channel device from the market. Twenty study patients had been implanted with the device. This decision has resulted in the limitation of treatment assignment to one of two multichannel devices. Only 80 patients in all will be accrued. Eligible patients include post-lingual bilateral pro-

foundly deaf individuals who receive no benefit from appropriate amplification. Patients eligible for randomization must have no radiologic evidence of gross bony overgrowth of the cochlea. Intensive audiologic evaluations will be completed at 1, 3, 12, and 24 months after initial stimulation. Additional yearly assessments of the outcome measures of interest will be completed for each patient until the conclusion of the study.

**Progress**—Currently, 79 patients have been randomized to the protocol. All implanted patients have received their assigned device, with the exception of two patients who received a secondary (single-channel) device. Early data regarding benefit from implantation are encouraging. Quality of life measures suggest that patients are pleased with the early effects of cochlear implantation. The conduct of the study is progressing without difficulties.

#### **Publications Resulting from This Research**

None reported.

### [489] Non-Auditory Factors Affecting Hearing Aid Use in Elderly Veterans

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**Sponsor:** VA Rehabilitation Research and Development Service (Pilot Project #C952-PA)

**Purpose**—This pilot project examined non-auditory factors influencing the successful use of hearing aids in elderly veterans. These included cognitive status, fine motor coordination, family support, and visual

acuity, all of which are frequently mentioned in literature concerning amplification for the hearing-impaired elderly. Previously, the influence of these variables had not been evaluated systematically in an



effort to predict outcome with hearing aids. The goal of this study was to review, isolate, and assess non-auditory factors that can be measured in a systematic way.

**Methodology**—Thirty elderly male veterans were initially enrolled as subjects. None had prior experience with hearing-aid use. Sixteen subjects with an average age of 69.0 years completed all phases of the study. As expected, the degree of hearing loss was highly variable among these subjects, though most showed a symmetrical, gradually sloping threshold configuration.

**Progress**—At an initial appointment for hearing-aid evaluation, each subject was administered the Hearing Handicap Inventory for the Elderly (HHIE). The mean score for the sample was 40.1, indicating a mild-to-moderate perceived handicap. The subjects were then screened for mental status using the Short Portable Mental Status Questionnaire (SPMSQ). Mean SPMSQ was 0.67, indicating intact intellectual function for the group. One subject had a score of 3, and one a score of 4, indicating mild intellectual impairment. Fine motor coordination was assessed by measuring the time necessary to place a battery in the battery compartment of the hearing aid selected for dispensing. The average of the three trials was considered the score for this variable. Mean score for the sample was 8.2 seconds with a range of 3-16 seconds. The next factor studied was visual acuity. Corrected vision was screened using a Snelling Chart. Scores are given as a percentage, with 100 percent equating to 20/20. Average visual acuity for the group was 96.2 percent. A Social Network Survey was developed as an attempt to assess the support each subject would be likely to receive with the adjustment to hearing-

aid use, and with the maintenance and care of his hearing aids. Each subject had at least one significant other, and as a group the sample reported an average of 4.6 people that they could count on for support. Most subjects reported knowing their primary significant other for at least five years, and had daily contact with them.

All subjects were fitted with binaural hearing aids. No less than 4 months following the receipt of the hearing aids, each subject was reevaluated on all measures. Correlation coefficients for tests of auditory function between initial and follow-up sessions ranged between 0.82 and 0.98.

**Results/Implications**—Mean score of the HHIE at the follow-up appointment was 14.6. This is an average change of 25.9, and represents a significant reduction in perceived hearing handicap. A series of paired *t*-tests indicated that no measure of the independent variables (mental status, fine motor coordination, visual acuity, and social support) showed any significant change between initial and follow-up sessions. Most of the sample in this pilot study had minimal deficits for the non-auditory factors chosen for study. The pilot study data set is not large enough to assess the effects of the predictor variables by means of a multiple-regression analysis. Based on this outcome, it is imperative to obtain a sufficient sample size that will include subjects with abnormal findings on these factors.

This pilot study has demonstrated that the objective measures used to evaluate non-auditory function are feasible and can readily be obtained at the same time as a hearing aid evaluation, without subject fatigue.

#### **Publications Resulting from This Research**

None reported.

### **[490] Coupler to Real Ear Transformations for Hearing Aid Selection: A Pilot Study**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C970-PA)

**Purpose**—Data which serve as the basis for the electroacoustic selection of hearing aids are most

commonly those gathered in the audiological evaluation. These measurements are typically made with



standard audiometric earphones (TDH-39, 49, or 50). The sound pressure levels (SPLs) generated by these earphones are specified as the output developed in a NBS-9A 6 cm<sup>3</sup> coupler. In contrast, the electroacoustic characteristics of hearing aids are specified by examining their output in a HA-1 or HA-2 2 cm<sup>3</sup> coupler. Since there is not a one-to-one relationship between the two different couplers, it is difficult to translate thresholds, maximum comfort level (MCLs), or loudness discomfort level (LDLs) under standard earphones (value specified in a 6 cm<sup>3</sup> coupler) to a predicted MCL or LDL with a hearing aid (value specified in a 2 cm<sup>3</sup> coupler).

The purpose of this pilot project proposal was to develop and test a method for comparing SPLs generated in real ears with those in 6 cm<sup>3</sup> and 2 cm<sup>3</sup> couplers. These obtained differences would, among other things, allow the audiologist to convert dB HL readings to output in a 2 cm<sup>3</sup> coupler. Thresholds, MCLs, LDLs, etc., could then be obtained under standard earphones and converted to 2 cm<sup>3</sup> coupler values for hearing aid selection purposes. Data analysis will also provide information concerning real ear-6 cm<sup>3</sup> coupler differences, real ear-2 cm<sup>3</sup> coupler differences, and 6 cm<sup>3</sup>-2 cm<sup>3</sup> coupler differences. These values should be of interest to the clinical audiologist, as well as to other auditory researchers desiring to specify more accurately the presentation levels of their stimuli.

**Methodology**—The group consisted of 25 persons having middle ear pressure within normal limits and a normal otoscopic examination.

An ER-3A tubeophone and a standard audiometric earphone were coupled to the subject's ear. A probe tube from a commercial probe tube microphone system was inserted to within 5 mm of the tympanic membrane.

With the probe tube in this location, the output of the tubeophone and earphone were adjusted until 75 dB SPL was measured in the ear canal. The tubeophone and foam plug were then coupled to a HA-1 2 cm<sup>3</sup> coupler and the earphone was coupled to a 6 cm<sup>3</sup> coupler and the outputs were measured. The difference between the outputs for the same SPL in the ear canal will then represent the real ear-2 cm<sup>3</sup> coupler difference. Given that all measurements are made with the same SPL in the ear canal, these data were compared and manipulated to produce the following comparisons: 6 cm<sup>3</sup>-2 cm<sup>3</sup>, 6 cm<sup>3</sup>-real ear, 2 cm<sup>3</sup>-real ear, and dB HL to 2 cm<sup>3</sup>.

**Results**—Data have been collected and analyzed for all subjects. The study has produced transformations for converting from the real ear to 2 cm<sup>3</sup> coupler, real ear to 6 cm<sup>3</sup> coupler, 6 cm<sup>3</sup> coupler to 2 cm<sup>3</sup> coupler, and dB HL to 2 cm<sup>3</sup> coupler. These results should be of value to audiologists and those wishing to know the real ear presentation levels of auditory signals. The specific results are too extensive to report in this brief summary.

#### **Publications Resulting from This Research**

None reported.

### **[491] Measurement and Prediction of Benefit from Amplification**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C344-RA)

**Purpose**—The goals of this project are to determine the amount of benefit typically received from hearing aids in everyday life, and to develop methods of quantifying and predicting hearing aid benefit.

**Progress**—In the past year, a standardized, 66-item self-assessment inventory for the measurement of

hearing aid performance in everyday life was completed. This instrument is called the Profile of Hearing Aid Performance (PHAP). It quantifies hearing aid performance in terms of communication in three types of everyday environments and the effects of amplified environmental noises.

An investigation of hearing aid benefit, quantified in terms of improved speech intelligibility on



the Connected Speech Test (CST) is almost completed. Aided performance is measured for three matched groups of hearing-impaired listeners. Each group is assigned to one typical listening environment. Three different hearing aids are fitted to each subject, and benefit is measured for both audio-only and audio-visual speech signals.

Investigations in progress include the following: 1) the correspondence of subjective and objective speech intelligibility measurements in elderly hearing-impaired listeners; 2) measurement of hearing aid benefit using aided and unaided response time in a speech intelligibility test; 3) comparison of two self-assessment instruments, the Profile of Hearing Aid Benefit (PHAB) and the Intelligibility Rating Improvement Scale (IRIS) for measurement of hearing aid benefit; and, 4) the effect of hearing aid maximum output on measures of speech intelligibility and loudness perceptions in the laboratory and in everyday life.

**Results**—Internal consistency reliability for the PHAP scales range from 0.70 to 0.91. Retest correlations range from 0.69 to 0.88. Critical differences have been computed to facilitate comparison of individual scores.

## [492] Studies on Amplification Selection for the Hearing-Impaired Veteran

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C307-RA)

**Purpose**—The major purpose of this study is to evaluate the reliability and validity of three different hearing-aid selection procedures: the revised National Acoustics Laboratory (NAL-R) method, the Memphis State University method, and a modified version of the traditional Carhart comparative speech testing method. Data collected will also allow us to evaluate: 1) changes in user satisfaction and measured performance over a 1-year period following the hearing aid fitting; 2) the correspondence between laboratory measurements and the results of questionnaire data; 3) the correlation between behavioral thresholds, real-ear *in situ* responses, and

Preliminary analysis of the hearing aid benefit data indicates that the amount of speech intelligibility improvement provided by newly-fitted hearing aids varies with listening environment and ranges from about 15 percent to 0 percent. Benefit does not appear to be very sensitive to moderate changes in frequency response. Benefit is about the same for both audio-only and audio-visual speech.

Preliminary results on some of the investigations in progress include the following: 1) some elderly hearing-impaired listeners substantially underestimate their own ability to understand connected speech as measured with the CST; and, 2) the PHAB and IRIS inventories appear to give somewhat different estimates of hearing aid benefit.

### Publications Resulting from This Research

**Distribution of Short-Term RMS Levels in Conversational Speech.** Cox RM, Matesich JS, Moore JN, *J Acoust Soc Am* 84:1100-1104, 1988.

**Use of the Connected Speech Test (CST) with Hearing-Impaired Listeners.** Cox RM, Alexander GC, Gilmore C, Pusakulich KM, *Ear Hear* 9(4):198-207, 1988.

**The Connected Speech Test Version 3: Audiovisual Administration.** Cox RM, Alexander GC, Gilmore C, Pusakulich KM, *Ear Hear* 10(1):29-32, 1989.

**Development of the Speech Intelligibility Rating (SIR) Test for Hearing Aid Comparisons.** Cox RM, McDaniel DM, *J Speech Hear Res* 32:347-352, 1989.

results of electroacoustic analysis in a 2 cc coupler; and, 4) factors such as certain audiologic patterns or the presence of other handicaps which might influence ultimate user satisfaction with a hearing aid.

**Methodology**—This study comprises 300 subjects: 100 will be placed into each of the three selection protocols. Prior to the purchase of hearing aids, and at periodic intervals thereafter, each subject and a "significant other" will be administered a series of questionnaires including the Hearing Performance Inventory (HPI) revised, the Hearing Handicap Inventory for the Elderly (HHIE) short form, the



Hearing Aid Performance Inventory (HAPI), and the Sickness Impact Profile (SIP). Screening will also be performed for visual or mental handicaps.

Hearing aid fitting and evaluation will follow the protocol pertinent to the particular selection procedure. A FONIX 6500 real-ear measurement system will be used to verify the spectrum of the aided signal delivered to the eardrum. Once the hearing aids are adjusted to closely approximate the desired response, the Speech Perception in Noise (SPIN) test and the Nonsense Syllable Test (NST) will be used to indicate improvement in speech intelligibility. Behavioral measurements of functional gain will also be obtained.

Subjects will return at approximately 1 month, 6 months, and 1-year intervals after the hearing aid fitting for follow-up procedures. At these sessions, laboratory measurements will be re-obtained. A battery-exchange program will be conducted on a subgroup of the subjects, and is designed to validate subjective reports regarding frequency of hearing aid use.

**Progress**—In the past year, data collection was initiated and is proceeding. Unfortunately, because of decreased hearing aid sales (a reflection of the

national trend) at the Bill Wilkerson Hearing and Speech Center, data collection has proceeded at a slower pace than anticipated at this site. In addition, we found that the clinical staff at both sites required a long period of training to ensure accurate data collection. The clinicians are now well-versed in the protocol and, with increased marketing of services, hearing aid sales are expected to increase. Thus, the rate of data collection should also show an increase over the next few months.

**Preliminary Results**—Data collected on 20 subjects are being entered into the computerized database. At this point, there is inadequate data for purposes of statistical analysis, although some initial qualitative observations can be noted. First, it is clear that the potentiometers on commercially available in-the-ear hearing aids do not always allow adequate adjustment of frequency response for matching with prescribed target gain. Second, it seems that fittings under the Carhart procedure may result in generally similar frequency response configurations to those obtained with a prescription formula.

#### **Publications Resulting from This Research**

None to date.

### **[493] Development of a Digital Hearing Aid and Computer-Based Fitting Procedure: Phase II**

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**Sponsor:** VA Rehabilitation and Development Service (Project #C203-DA)

**Purpose**—The purpose of this research is to develop a novel form of hearing aid and a companion fitting procedure based on digital signal processing technology with due consideration given to low-power, custom Very Large Scale Integrated (VLSI) design and fabrication technology.

**Methodology**—A digital approach provides the flexibility of adjustment and control of auditory signal processing required to match the patient's hearing impairment. By incorporating the Digital Hearing Aid (DHA) into the hearing assessment and fitting procedure, variables such as the acoustics of the

earmold and head can be directly accounted for in fitting the aid.

**Results**—The major development work, including hardware and software for a new table-top hearing aid system, as well as a PC-based fitting system, has been completed. The new table-top system has made it possible to test hearing-impaired subjects with interim versions of the low-power, custom VLSI circuitry. Preliminary experiments with computer-aided fitting strategies and further evaluation of logarithmic arithmetic using the digital signal processor circuitry have been completed. In addition,



studies of various methods of adaptive feedback equalization and noise suppression have been completed and appropriate algorithms have been developed. Lastly, we have begun working to develop the specification for a commercial unit.

We have developed and are currently using a new method of adjusting and verifying the gain-frequency settings of the DHA that appears to work quite well. The method uses an external sound probe system to measure insertion gain while the patient is wearing the DHA. First, the unaided sound pressure is measured as a function of frequency, with a probe-tube microphone in the patient's unoccluded ear canal. Then, the aided sound pressure in the ear is measured with the DHA coupled to the patient's ear with a custom earmold and set to nominal gain values in its linear range of operation. The host system then computes: 1) the difference between the aided and unaided sound pressure levels; and, 2) the difference between this result and the desired prescriptive insertion gain. The DHA is then adjusted to make up the difference and a second measure of sound pressure is taken.

In practice, it takes only a few iterations, at most, to arrive at the desired insertion gain setting within only a few decibels of error. The entire procedure, including setting of parameters of the DHA, is automated and controlled by a program that was written for a PC-based host system.

The design of the DHA has evolved considerably during this current contract period. The analog circuitry includes a preamplifier, pre-emphasis shaping filter, anti-aliasing filter, analog-to-digital converter, and digital-to-analog converter. The digital circuitry includes four independent parallel channels comprised of a filter-limit-filter structure that provides instantaneous signal compression. Adaptive filters for feedback equalization and noise reduction have been added to the model to increase the versatility of the design. Filter transfer characteristics, parameters that control the adaptive filters, channel gains and limiting, and other parameters of the DHA can be programmed in almost arbitrary ways by downloading a series of coefficients into the serial port. The hearing aid settings can be retrieved by reading out a series of coefficients from the serial port.

**Future Plans/Implications**—Future plans include continued evaluation of the full-featured digital hearing aid, further refinement of processing algorithms, further development of the automated, computer-based method of fitting and evaluation, and commercialization of the design.

#### **Publications Resulting from This Research**

None reported.

## **[494] Basic Mechanisms and Rehabilitative Strategies for Presbycusis: Part I**

**Brenda M. Ryals, PhD**

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #C251-2RA)*

**Purpose**—Over the past three years, we have determined the general auditory morphological and electrophysiological characteristics of the coturnix quail throughout its entire actuarial life. This information is now being used as a basis for studying the influence of environmental and systemic toxins on the auditory system during the aging process. Specific questions are: 1) Is the anatomo/functional response to traumatic and toxic events different in the senescent auditory end organ? and, 2) Is the

potential for recovery different during the aging process?

**Methodology/Results**—In the first experiments adult quail were exposed to an acoustically traumatic tone for 12 hours. Quail were allowed to survive from 0 to 90 days. Inner ears were fixed, dissected free, embedded in plastic, and sectioned serially from base to apex at each survival interval. Both tall and short hair cells were significantly



reduced in number, 10 days following trauma. However, after 60 to 90 days both cell types had recovered to nearly normal numbers. Ganglion cells, on the other hand, decreased in number and did not recover.

In order to determine whether the recovery of cell number represented actual regeneration of new cells, a second set of experiments was performed. Both young adult and old adult quail were exposed to the same acoustic trauma as in the first experiment. Immediately after acoustic trauma, the birds received a series of injections of  $^3\text{H}$ -thymidine. Autoradiography showed incorporation of  $^3\text{H}$ -thymidine over hair cells in both age groups. Tall hair cell labeling occurred less often than short hair cell labeling; support cell labeling occurred most often. There was no significant difference in the amount of hair cell loss or labeled cells between age groups.  $^3\text{H}$ -thymidine labeling was not seen outside the damaged area. Labeling was seen only once in one control bird (over 200 sections examined from each bird).

In order to determine whether these "new" hair cells were receiving innervation,  $3\mu$  thick sections were re-embedded and analyzed by means of electron microscopy. Hair cells which were positively identified as having undergone mitotic activity were found to have either no synaptic innervation, or in one case, efferent innervation only. Results have been analyzed only for 10 days following trauma.

Compound VIII nerve action potential thresholds have also been measured in young and old quail following acoustic trauma. An initial 30-40 dB

threshold shift recovered to nearly normal within 48 hours. Rate of recovery was not significantly different between age groups. Since there is no current evidence for re-innervation of afferent fibers within 10 days of trauma, and since ganglion cell degeneration continues for 90 days following trauma, it seems unlikely that this functional recovery represents the functional status of the new hair cells.

So that we might know whether this potential for regeneration could be generalized to other traumatic or toxic events, the ototoxic drug gentamicin was administered. The initial response to gentamicin ototoxicity was a 30 percent reduction in hair cell number and a significant shrinkage in cochlear neuronal size. After 40 days, hair cell number and neuronal size had returned to nearly normal. Birds treated with gentamicin and injected with  $^3\text{H}$ -thymidine showed clearly labeled hair cells and support cells in the region of initial hair cell loss. These results confirm the capacity for hair cell regeneration after ototoxicity.

**Implications**—These studies show that hair cells can regenerate after terminal mitosis in the inner ear of birds. In addition, they show that this regenerative potential is retained throughout life into senescence. Although the location and mechanism of activation of the precursor cells responsible for mitotic activity are yet to be identified, the potential may exist to restore inner ear sensory elements after injury or disease in other species. This potential for restoration of sensory elements does not appear to be limited by age.

## Basic Mechanisms and Rehabilitative Strategies for Presbycusis: Part II

**Purpose**—Concurrent with the anatomical and electrophysiological studies in birds, we are exploring the possibility of an altered preference for frequency response and/or gain characteristics of amplification in the elderly human hearing-impaired population. Specific questions are: 1) Is there an altered preference for frequency and/or gain characteristics of amplification devices in the elderly? 2) Do any particular formula approaches approximate these characteristics better than others? 3) Does the use of noise reduction influence these desired frequency/gain characteristics? and, 4) Is the digital

noise reduction produced by the Nicolet Phoenix hearing aid preferable to non-noise reduction when frequency/gain characteristics are optimal?

**Progress/Results**—In our first set of experiments, we have determined the actual use gain and frequency response characteristics of currently worn hearing aids in two populations: young (<60 years, mean age = 51) and old (>75 years, mean age = 77). Audiometric configuration and degree were equated for all subjects. All subjects had used their in-the-ear hearing aids for more than one year and



reported that they were well satisfied with them. Real ear insertion gain was measured with the volume control of the hearing aid set to a comfortable listening level using a Rastronics CCI-10 probe microphone system. Normal use gain for frequencies from 250 Hz to 4,000 Hz was compared between old and young groups. Four formulae for predicting gain were also applied to the audiometric thresholds of each group in order to determine if the use gain for each group could be predicted by a formula approach.

No significant difference was found between the use gain preferred by older and younger subjects. When the four formulae were applied, most were fairly accurate in their estimation of use gain up to 2,000 Hz. Above 2,000 Hz, all formulae over-predicted gain currently in use. The revised National Acoustics Laboratory (NAL) formula and the one-third gain rule provided the best estimate of use gain.

While the results of this study suggest that age does not significantly influence frequency/gain response amplification characteristics, this interpretation must be tempered by two factors: 1) because most of the subjects in this study were over the age of 40, the two age groups may have been insufficiently diverse to show actual age differences; and, 2) preferred gain was limited to the use gain currently provided by the subject's hearing aid. Use gain may not be optimal gain. Thus, the consistent finding of less user gain at 3,000 Hz than predicted by any formula may reflect limitations of the subject's own hearing aid rather than a true preference for less high frequency gain.

In order to address this issue, the Nicolet Phoenix digital hearing aid was used in a paired comparison matrix program. Subjects were able to choose various alterations in frequency/gain characteristics for high and low frequencies. Preliminary results indicate that, when given the choice of the

NAL predicted gain at 3,000 Hz versus gain more typical of their current hearing aids (approximately 8 dB lower than NAL), subjects choose the NAL response. All response characteristics offered and chosen were measured using a real ear probe microphone system. No significant differences have been found in quiet or in noise. Thus, results to date validate the revised NAL prescriptive formulae for predicting user chosen optimal frequency/gain characteristics.

**Future Plans/Implications**—Future studies will address the influence of noise reduction on preference as well as optimal response as determined by objective measures such as speech discrimination. These results suggest that the frequency/gain response characteristics preferred by the elderly hearing-impaired population can accurately be predicted using the revised NAL prescriptive approach. Future studies, however, must address the issues of appropriate amplification characteristics under adverse conditions such as uncomfortable intensity input and background noise.

#### Publications Resulting from This Research

- Ganglion Cell and Hair Cell Loss in Coturnix Quail Associated with Aging.** Ryals BM, Westbrook EW, *Hear Res* 36:1, 1988.
- Hair Cell Regeneration After Acoustic Trauma in Adult Coturnix Quail.** Ryals BM, Westbrook EW, Rubel EW, *Assoc Res Otolaryngol* 11:34, 1988.
- Hair Cell Regeneration After Acoustic Trauma in Adult Coturnix Quail.** Ryals BM, Rubel EW, *Science* 240:1774, 1988.
- Recovery of Hair Cell Number in the Chick Basilar Papilla After Gentamicin Toxicity.** Westbrook EW, Ryals BM, Lippe W, *Assoc Res Otolaryngol* 11:50, 1988.
- Regeneration of Hair Cells in the Chick Basilar Papilla Following Gentamicin Toxicity.** Lippe WR, Ryals BM, Westbrook EW, *Assoc Res Otolaryngol* 82:96, 1989.
- Continued Ganglion Cell Loss After Hair Cell Regeneration.** Ryals BM, Ten Eyck B, Westbrook EW, *Hear Res* (in press).
- Differences in Hearing Aid Gain as a Function of Age.** Ryals BM, Auther LL, *Hear Instrum* (in press).

## [495] Auditory Alarms Project

**J. Scott Hauger; Joyce C. Rigby**

Applied Concepts Corporation, Winchester, VA 22601

**Sponsor:** Architectural and Transportation Barriers Compliance Board

**Purpose**—The Auditory Alarms Project was sponsored by the U.S. Architectural and Transportation

Barriers Compliance Board (ATBCB) to conduct human factors research on the characteristics of



audible alarm signals that might benefit persons with hearing impairments. The purpose of this research was to consider modifications to the Minimum Guidelines and Requirements for Accessible Design (MGRAD), and to develop technical assistance materials in light of the results of human factors testing.

**Methodology**—Six commercially available fire alarm signals and four non-alarm sounds were used. Sixty paid volunteers were chosen from the members of Self Help for Hard of Hearing Persons, Inc. (SHHH). Testing was in three stages. Test A was a paired comparison test which had the subject decide which of two sounds was “more like an alarm.” All ten sounds were presented in all possible combinations at sound pressure levels of 85, 95, and 105 dBa. Test B required the subject to decide if each sound was an alarm signal or not, when presented at each intensity level. Test C was the same as Test B, with reverberation added.

**Results**—Testing concluded that sound characteristics did make a difference in hearing-impaired subjects' response to an alarm signal. An observation of test results led to two hypotheses: 1) an alarm signal consisting of three or four clear tones is more effective than signals with a single tone,

reverberating tones, or broad spectrum tones; and, 2) an alarm signal with two-phase, periodic variations is more effective than a steady sound. It was also found that louder alarms are more effective, especially up to about 95 dBa in sound pressure, and that within the range of 85–105 dBa, sound characteristic is more important than sound pressure for recognizability.

Based upon test results, a placement and cost analysis was performed, using similar methods to those employed in the Alarms Documentation Project and Visual Signals Project. These analyses showed that: 1) for standard room configurations, there is a need for one signal appliance in each room in order to achieve either visual signal coverage or audible signal coverage at 95 dBa; and, 2) it costs approximately the same to install audible signals to achieve 95 dBa minimum sound pressure in a building, as to install visual signals.

Visual signals have the advantage of being able to alert people who are profoundly deaf, and cannot hear an audible alarm signal of even 95 dBa. They also have the advantage of providing a second stimulus, i.e., a reinforcement, for the general population.

#### **Publications Resulting from This Research**

None reported.

### **[496] Sound Recognition Device**

**J. Scott Hauger; Joyce C. Rigby**

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**Sponsor:** *National Institute for Disability and Rehabilitation Research*

**Purpose**—The objective of this project is to develop a new generation sensory aid to provide visual information on important environmental sounds. It is anticipated that the sound recognition device will be programmable by the user and will utilize the auditory signatures of sounds to accurately recognize and identify each sound.

**Progress**—A laboratory prototype sound recognition device has been developed utilizing an IBM PC/XT, equipped with a Texas Instruments Speech Board II. Environmental testing of this version of the sound recognition device has been performed to evaluate

the functionality of the sound recognition hardware and software algorithms. Environmental testing utilized actual sounds based on sound categories identified in a user survey. Test results indicate reliable sound recognition for mechanically- or electronically-reproduced sounds, such as a door bell, or telephone, etc. Enhancements to this prototype will produce a second prototype for field-testing in year three of this project.

**Future Plans**—In year three, the sound recognition device will be redesigned as a portable unit. The software will be enhanced according to the conclu-



sions drawn from laboratory test results. The new prototype will be used in field testing by members of Self Help for Hard of Hearing People, Inc. The results from these tests will be incorporated into the final design.

#### **Publications Resulting from This Research**

None reported.

### **[497] Auditory Redundancy of Computer Information for Hearing-Impaired Individuals**

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**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—Currently, people with hearing impairments have little or no difficulties in using computers. The use of sound as a standard feature has been minimal, usually no more than a “beep.” However, the increasing sophistication of synthetic and digital speech technologies has made it easier and more desirable for computer companies to consider incorporating voice output into their products. This would probably take the form of standard voice features in the operating system (such as voice output of error messages) or available voice features that could be “called” from the operating system by application programs.

**Methodology**—As a first step in addressing these problems, a proposal has been made for the incorporation of a “hearing impairment flag” in standard computer operating systems. Such a flag would appear along with other control settings for the operating system. The flag would provide a means for the user to signal cooperating software and operating systems that the user cannot hear any sounds emitted by the computer. Programs and operating systems could then accompany any beeps with some type of visual event on the computer screen. Simple beeps might correspond to a flashing of the menu bar or screen border. More complex tonal output could be presented to the user in some type of graphic that would appear on the screen.

The hearing impaired flag also presents the possibility of “closed captioning” for computer programs. Programs sending voice messages to the user could read the flag to determine if a corresponding text message should also be sent. In the future, the closed captioning function may be able to be executed entirely through an operating system call.

**Progress**—The proposal for a hearing impairment flag is being fed to computer companies which are pursuing specific disability development efforts. It is also being incorporated into the “Considerations” document of the Industry/Government Cooperative Initiative on Computer Accessibility, and distributed to any other interested companies, organizations, or individuals through that channel.

**Results**—The goal of this project is the eventual incorporation of the hearing impairment flag into new computer operating systems. Should operating systems emerge that provide voice output, the effort will also focus on closed captioning through the operating system.

#### **Publications Resulting from This Research**

None reported.

## C. Speech Impairment

### 1. General

#### [498] Computer Assisted Speech Evaluation Expert System

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**Sponsor:** *VA Rehabilitation Research and Development Service (Project #C468-RA)*

**Purpose**—This research program is devoted to developing and testing specific computer and instrumental procedures designed to measure aspects of speech and speech-related function in subjects with disordered speech. Software is being developed to extract and analyze speech acoustic, aerodynamic, and physiologic data during connected speech and specific diagnostic maneuvers. Expert systems are being developed to provide interpretation of obtained speech deviance profiles and to provide advice regarding optimum sequencing of diagnostic tasks.

**Progress**—The initial period has focused on development and validation of acquisition and quantitative analysis procedures that result in objective measures of speech function. A clinical interface shell has been developed to house modules related to

specific diagnostic protocols. This shell provides instructions, context-sensitive help, calibration procedures, data collection, and quantitative analysis. Pilot data have been collected on more than 120 normal and disordered subjects for various protocols. Expert systems related to each protocol are now in development.

**Future Plans**—Additional work will provide formal descriptive measures for clinical groups of speech disordered subjects and for normal subjects. These data will be studied in relation to human perceptual judgment and will be used to evaluate and refine the expert system components.

#### **Publications Resulting from This Research**

**None reported.**

#### [499] Acoustic Vowel Measures Following Radiation Therapy to the Larynx

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Department of Otolaryngology, Medical College of Georgia, Augusta, GA 30910

**Sponsor:** *VA Rehabilitation Research and Development Service (Project #C336-RA)*

**Purpose**—Patients who have undergone radiation therapy for laryngeal carcinoma confined to a true vocal fold(s), in the absence of positive neck nodes or metastases, are often referred for voice therapy because of a residual hoarse voice. Clinically, it is known that hoarseness diminishes over time, following the completion of radiation therapy. The course and degree of voice change during and following radiation therapy, however, have not been thor-

oughly documented. Having such knowledge could greatly influence the decision-making process regarding the evaluation, management, and dismissal of patients who have completed radiation therapy, and are being considered for voice treatment. The objective of this study is to provide quantifiable acoustic data that are correlatively associated with voices produced by patients presenting such laryngeal carcinoma.



**Methodology**—Twenty patients meeting the above criteria and 20 normals will be entered into the study. Acoustic measures along with auditory and visual judgments will be collected prior to, during, and at 1-month intervals for 1 year following completion of radiation therapy.

Each patient will sustain 5 test vowels at a comfortable pitch and loudness for a minimum of 5 seconds for each vowel. All vowel samples will be acoustically analyzed to obtain spectral noise levels and correlated to auditory and visual measures.

**Progress**—Five patients were entered into the study prior to the project being moved to the VA Medical

Center in Kansas City, MO. Due to a lack of patients meeting the requirements of the study, data collection was discontinued. The study, although discontinued, appears to have merit and will be revised and resubmitted to include other populations of patients.

#### **Publications Resulting from This Research**

**Spectral Noise Level Measurements Used To Track Voice Improvement In One Patient.** Trullinger RW, Emanuel FW, Skenes LL, Malpass JC, *J Commun Disord* 21, 447-457, 1988.

**Airflow, Volume, and Duration Characteristics of Sustained Vowel Productions of Normal-Speaking Children.** Trullinger RW, Emanuel FW, *Folia Phoniatr* (in press).

### **[500] Development and Evaluation of an Expert System to Facilitate Efficient Matching of Disabled People to Communication Devices**

**Rob E. Garrett, BTech; Peter B. Andrews, BEd; Cathy F. Olsson, BAppSci; Barry R. Seeger, PhD**  
Rehabilitation Engineering Division, Regency Park Centre for Young Disabled, Kilkenny, SA 5009 Australia

**Sponsor:** *The Channel 7 Children's Research Foundation of SA, Inc.*

**Purpose**—The process of matching a disabled individual to an available communication system requires skilled and expert analysis of that individual's needs and capabilities. In Australia, no state has a complete range of communication devices available, so that providing access to a device for trial with a client is difficult. Therapists must therefore rely on product guides for information upon which to base their prescriptions.

Our aim is to produce an "Expert System" which will provide a consultative process, at the end of which a device or range of devices is recommended.

**Methodology**—A catalogue has been developed which describes in detail each of a range of communication devices (currently 12). These descriptions have formed the basis of selection rules in

the Texas Instruments Personal Consultant Plus Expert System.

**Progress**—The system now incorporates 60 rules, one or more of which leads to a conclusion at the end of the consultation. The conclusion is either that there is a suitable device or range of devices for the client, or that no conclusion is possible. Conclusions from the system have been reviewed by the team and found to be suitable.

**Future Plans**—A working system will be available to therapists as a consultation tool, and to education facilities as a training tool.

#### **Publications Resulting from This Research**

None reported.

## **[501] Assessment of the Effectiveness of a Small, High Quality Speech Synthesizer in Augmenting the Communication of Non-Speaking Individuals**

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**Sponsor:** *The Channel 7 Children's Research Foundation of SA, Inc.*

**Purpose**—To assess the effectiveness of a small, high quality speech synthesizer as an adjunct to the normal communication system of a non-speaking child. Communication interactions between a non-speaking child and an age-matched, natural-speaking peer, with and without the device are to be compared.

**Methodology**—Past research has shown that interactions between non-speakers and natural speakers are dominated by the natural speaker, who tends to initiate more topics, occupy more of the conversational space, and have greater control over the conversation. Non-speakers adopt a very passive role in these communication interactions.

Non-speakers are provided with a speech synthesizer containing four high quality voice phrases, which act as an adjunct to their normal communication device. The phrases allow the non-speaker to: 1) initiate conversation (e.g., "I've got something to tell you"); 2) continue conversation (e.g., "That's excellent"); and, 3) repair breakdowns (e.g., "Wait. I'll keep trying").

It is hypothesized that this device will aid the non-speaker in controlling the conversation, allowing a more active role in an interaction with a natural speaker.

**Progress**—Based on the results of a pilot study with one subject, an 11-year-old female, several modifications were made to the original design. The study showed that few breakdowns in communication occurred, but the non-speaker had difficulty in initiating conversation. The phrases contained in the device were modified to contain two initiators, one repairer, and one continuer. The pilot study also showed that training of the non-speaker's conversational skills was necessary.

Three students from the Regency Park Centre for Young Disabled, a 12-year-old girl, an 8-year-old boy, and an 8-year-old girl, and three age-matched peers from a local school are now participating in the study.

The students participate in a total of twelve 20-minute sessions conducted once a week, where they are video-taped talking with their natural-speaking peers. The first six sessions are baseline sessions to assess the effectiveness of the communication device alone in aiding the non-speaker. Minimal training in the use of the device is given. Sessions with the Alltalk communication device are alternated with sessions without the device.

After six sessions of training in initiating, continuing and repairing conversations will be given. This will be followed by six sessions with/without the use of the Alltalk communication device, to assess the effectiveness of training in conversational skills as well as the communication device.

**Results**—We have developed a format to use for real-time and video-based analysis of communication interactions in terms of topic initiation and control, and occurrence and repair of breakdowns.

**Implications**—The research is reinforcing our belief in the usefulness of providing highly intelligible phrases that are quickly and easily accessed for conversational control, maintenance, and repair. The experience has raised further questions regarding the relative importance of user training, peer training, device intelligibility, and vocabulary composition and organization in achieving ease and effectiveness of communication.

### **Publications Resulting from This Research**

None reported.



## [502] Determinants of Intelligibility in Dysarthric Speech

**H. Timothy Bunnell, PhD**

Applied Science and Engineering Laboratories, Alfred I. duPont Institute and The University of Delaware, Wilmington, DE 19899

**Sponsor:** *Nemours Foundation*

**Purpose**—This project will conduct studies of the articulatory, acoustic, and perceptual characteristics of dysarthric speech. The goal of this research is to determine characteristics that are most disruptive to intelligibility.

Dysarthria may involve a variety of deficits in the control of articulator motion including, for example, rigidity, imprecise movement, unusually slow movement, and impaired ability to coordinate the relative timing of motion for different articulators. Some of these deficits may prove more disruptive to overall speech intelligibility than others. Moreover, different deficits may affect the intelligibility of particular phonetic segments in different ways.

**Methodology**—Perception experiments are planned to assess the intelligibility deficits associated with various forms of dysarthria both in overall terms

and in terms of the effects on specific speech segments. In these experiments, digital signal processing techniques will be used to systematically alter specific characteristics of recorded dysarthric speech that are targeted for study while leaving other characteristics unaltered. In particular, the signal processing will be used to match dysarthric productions to normal productions of test words on a single experimental dimension.

**Future Plans**—Different experiments are planned to explore different “dimensions” such as syllable timing, vowel color, and formant transition rate. In this way, it will be possible to evaluate the relative importance of each dimension in determining the intelligibility of dysarthric speech.

### **Publications Resulting from This Research**

**None reported.**

## [503] Developing HAMLET: An Emotional Synthetic Speech System

**Iain R. Murray; John L. Arnott; Alan F. Newell**

Microcomputer Centre, Dundee University, Dundee DD1 4HN Scotland

**Sponsor:** *The Science and Engineering Research Council (UK)*

**Purpose**—The Helpful Automatic Machine for Language and Emotional Talk (HAMLET) has been in development at our Centre for the past 3 years. The system is a prototype for a synthetic speech system which incorporates emotion effects into the output speech.

The project came into being after three DECtalk speech synthesizers were donated to the Microcomputer Centre. Because the speech quality of these devices was so good, staff wondered if emotion effects could be added to their output. If so, this would be of benefit to the vocally-handicapped users who use the Predictive Adaptive Lexicon (PAL) and Conversation Helped by Auto-

matic Talk (CHAT) communication aids, as well as potential users of any other communication system that can use a speech synthesizer as an output device.

**Progress/Methodology**—To answer this question, a literature search on speech synthesizer technology and how emotion could be added was conducted. It was surprising to find that no one had previously tried to add emotion into synthetic speech. Research on human vocal emotion has also been fragmented, to say the least, but by pooling the results of various studies, it was possible to build up a model of the principal vocal effects of some common emotions.

The six basic emotions about which the most information was available (anger, happiness, sadness, grief, fear, and disgust) were chosen as starting points for the prototype emotional synthetic speech system, HAMLET.

The HAMLET development system is based around a rulebase of speech effects, the rules having been constructed to mimic the effects described in the literature, and it uses these rules to modify the appropriate control instructions for the speech synthesizer. The rules are divided into three parts, and these alter the voice quality of the synthesizer, the duration of the phonemes in the utterance, and the pitch contour of the utterance. For example, a sad voice would be slower and quieter than normal, have a narrow pitch range with downward inflections, and a slight trembling in the voice. In contrast, happiness would cause an increase in speech rate and loudness, and have a wider pitch range with upward inflections of greater magnitude.

Some experiments have been conducted in which naive listeners heard some HAMLET speech

and indicated which emotion was portrayed, and this has shown that, on the whole, recognizable emotions are being generated. A prototype version of the system has been incorporated into the CHAT conversation communication aid, and has been tested out informally with a handicapped user with some success.

**Future Plans/Implications**—Eventually, the HAMLET rulebase could be incorporated into any synthetic speech system to modify the output speech as required. Current work is now continuing on the project to improve the realism and range of emotions produced by the system, and further development could lead to a commercially-viable system within 5 years.

#### Publications Resulting from This Research

**HAMLET: Simulating Emotion in Synthetic Speech.** Murray IR, Arnott JL, Newell AF, in *Proceedings of Speech '88, The 7th FASE Symposium*, Edinburgh, 1217-1223, 1988.

## C. Speech Impairment

### 2. Hearing-Related

#### [504] Auditory Prosthesis for Sensorineural Hearing Loss

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C054-3RA)

**Purpose**—The object of this research is to determine the optimal design parameters and fitting procedures for a new multichannel compression hearing aid for patients with sensorineural hearing loss (SNHL). Previously, we have demonstrated that an initial 8-channel version of the aid was very effective in helping individuals with SNHL to recognize speech sounds in the presence of noise (a key problem for SNHL patients). The present work will include a systematic study of the following parameters of the multichannel compression hearing aid: 1) number of channels; 2) time constant of the compression; 3) location of the channel boundaries with respect to

the configuration of the hearing loss; 4) type of compression system; and, 5) shape of the compression function. The present work will also examine the importance of learning to use a multichannel compression hearing aid. Aspects of the previous results suggested that the performance of the subjects with the new aid had continued to improve throughout the study (over 40 hours of testing per subject).

**Progress**—The performance of the multichannel compression aid improves as the number of channels increases, up to 8 channels, and then the perfor-



mance is essentially constant from 8 to 16 channels. The experiments concerning the time constant parameter also are completed, but the detailed data analysis remains to be done. Constant time windows, the same in all channels, from 5 ms to 200 ms were used: in a second experiment, time windows varying inversely with frequency were compared with the 10 ms constant time window. Performance was measured in 15 SNHL subjects at five signal-to-noise ratios (S/N) with both a male and female voice. At this time, we have begun to measure the effect of the location of the bands with respect to the individual hearing loss configurations.

**Preliminary Results/Implications**—The performance of our multichannel compression system proved to be quite insensitive to the time parameter. Only

one-third of the subjects showed statistically significant differences among the six constant time windows (5, 10, 20, 50, 100 and 200 ms), and only two subjects showed statistically significant differences between the constant time window and time windows varying with frequency. It is encouraging that our multichannel compression system works as well with short as with long time windows, because both the construction cost and the physical size of a hearing aid incorporating such a system would increase with the duration of the required time window.

#### **Publications Resulting from This Research**

**Speech Discrimination with an 8-Channel Compression Hearing Aid and Conventional Aids in a Background of Speech-Band Noise.** Yund EW, Simon HJ, Efron R, *J Rehabil Res Dev* 24(4):161-180, 1987.

## **C. Speech Impairment**

### **3. Aphasia**

#### **[505] Hierarchical Computerized Language Treatment for Aphasic Adults**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C400-RA)

**Purpose**—Recent reports imply that microcomputers may be effective in providing language treatment for aphasic adults. The current project is based on earlier work by the investigators, and it expands the use of complex algorithms and hierarchically arranged tasks to deliver language treatment appropriate for each patient's level of severity. The purpose of the study is to develop hierarchically arranged reading and writing treatment software and test its effectiveness by comparing improvement in patients who receive computerized language treatment with that of patients who receive computer-stimulation ("non-language" activities), or no treatment.

**Progress**—A reading test, the Comprehension Communication Aphasia Test (CCAT), and reading and

writing treatment software have been written, coded, tested, and debugged. Half of our subject sample is currently enrolled or has completed the six-month treatment trial.

**Preliminary Results**—All subjects in the Computer Reading Treatment Group learned to use the software with minimal assistance from the experimenter within three sessions, ultimately completing between 82 and 153 treatment activities within the first three months of treatment. Comparison of standardized and CCAT test scores for the Computer Reading Treatment Group at entry, and after three-months' participation, indicated considerable improvement in overall reading, and verbal test scores. The Computer Stimulation Group also demonstrated im-

provement in overall and verbal test scores. The No Treatment Group showed little change on all language measures.

**Future Plans/Implications**—Additional patients are being recruited and assigned randomly to the three groups. The results of the investigation should demonstrate whether computerized reading and writing treatment for chronic aphasia is effective, and whether this type of treatment can be administered by a computer with minimal assistance from a clinician.

## [506] Cortical Auditory Evoked Potentials and Behavioral Measures of Aphasia

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C493-RA)

**Purpose**—The purpose of the project is to examine hemispheric processing of language by 20 stable, and 15 recovering aphasic patients, by using late auditory evoked potentials as direct electrophysiological measurement of hemispheric involvement.

**Methodology**—Subjects undergo a behavioral testing battery including the Porch Index of Communicative Abilities (Porch, 1967); the Boston Diagnostic Aphasia Examination Severity Index (Goodglass and Kaplan, 1973); a handedness questionnaire; and a bilateral hearing screening at 500, 1k, and 2k Hz. Evoked potential testing consists of a right hemisphere task (music), a left hemisphere task (listening to language), and a non-differentiating task (noise). While the subject is actively involved in processing the information in the task, evoked potentials to irrelevant auditory probe tones are used as the measure of hemispheric involvement in that task. Measurements of electrical activity are bipolar from frontal and parietal midline sites, as compared to

## Publications Resulting from This Research

**Effective Treatment Software for Aphasic Adults.** Katz RC, in *Integrating Theory and Practice in Clinical Neuropsychology*, E. Perecman (Ed.), Hillsdale, New Jersey: Lawrence Erlbaum Associates, Inc., 1989.

**A Comparison of Computerized Reading Treatment, Computer Stimulation, and No Treatment for Aphasia.** Katz RC, Wertz RT, Lewis SM, Esparza C, Goldojarb M, in *Clinical Aphasiology: 1989 Conference Proceedings*, T.E. Prescott (Ed.), Boston: College-Hill Press/Little, Brown & Co. (in press).

temporal sites on each side of the scalp. Stable patients will receive this paradigm on two separate occasions; recovering patients will be tested longitudinally at two-month intervals.

**Progress**—At this time, the evoked potential equipment has been acquired and is currently being calibrated and programmed for the auditory evoked potential protocol. Auditory stimuli for the language, music, and noise tasks have been prepared and recorded on audio tape for presentation to the subject. Intensity levels for the tasks and the tones have been measured and set. An event recorder has been adapted for the specific purpose of recording the behavioral response to the task by the subject and the matched response of the examiner for later behavioral scoring. Final mixing and stimuli presentation methodology is being completed.

## Publications Resulting from This Research

None reported.



## [507] Development of Microcomputer and Clinician Treatment Procedures for Aphasia

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C343-2RA)

**Purpose**—The use of microcomputers in the rehabilitation of brain-damaged patients continues to win popularity in some clinical settings. Cost-effectiveness, operational efficiency, and increased treatment time allocations without additional human resources are the high-tech features that bolster their acceptance and application. Yet data-based research in speech/language pathology concerning treatment efficacy remains sparse. The field presently lacks convincing data as to the efficacy of using microcomputers for the rehabilitation of aphasic adults. The purpose of the present study is to answer the following questions: 1) Are clinician assisted microcomputer treatment programs as efficacious in treating marked aphasic individuals as they are compared to treating moderate to mild aphasic individuals? 2) Is linguistic cueing hierarchy different for various types and levels of aphasic persons? and, 3) Can streamlining recueing the verb treatment package by eliminating and/or rearranging hierarchical levels be beneficial to overall language recovery in aphasic individuals ranging in severity and type?

The first objective of this investigation is to provide 21 aphasic adults of various severity levels an opportunity to achieve significant increases in the level of their communicative functioning, using a well established reliable treatment procedure. Objective Two is to establish the most effective linguistic cueing hierarchy for various types and levels of

aphasia in two treatment mediums; microcomputer/clinician-assisted treatment, and clinician-alone treatment. The third objective is to determine whether or not streamlining the treatment package can be efficacious to overall language recovery of aphasia by eliminating and/or rearranging treatment levels.

**Methodology**—To study treatment effectiveness, an alternating treatment design with multiple probes (single-case), is utilized. By using this type of design, baseline performance, the effects of treatment, maintenance of behavior, and generalization across treatment tasks can be easily viewed. All patients received two modes of treatment (clinician and microcomputer) daily, in a rapidly alternating fashion. The microcomputer and clinician treatment packages are identical in terms of types of stimuli, modality, and randomization of presentation, type of feedback, and scoring.

**Progress**—Procurement of all equipment for each research site (Denver-Massachusetts) has been completed. Finalization of all computer programming has been completed. The first patients have been identified for inclusion in the study and external baseline testing has been completed.

### **Publications Resulting from This Research**

None reported.

## [508] Chest Wall Kinematics in Alaryngeal Speakers: A Pilot Study

**Joseph J. Langhans, PhD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Pilot Project #C975-PA)

**Purpose**—The purposes of this exploratory descriptive study are to: elucidate chest wall kinematic

function in accomplished traditional esophageal speakers; and determine whether chest wall kinemat-

ics differ during speech production by traditional esophageal speakers comparable in body type, age, and level of speech development, but who differ according to the presence or absence of excessive stomal noise. The relation of the genesis of stomal noise to chest wall activity will be elucidated.

**Methodology**—Two groups of traditional esophageal speakers are being monitored during respiratory activities and utterance tasks in accordance with the kinematic method, a unique, noninvasive means with which chest wall function can be studied in alaryngeal speakers. Using magnetometers, electromagnetic transducer coils, the anteroposterior (A-P) displacement of the two-component chest wall, the rib cage (RC), and the abdomen (AB), are monitored. With movement, each component displaces

volume, and because changes in the A-P diameters of the RC and AB are related linearly to the volume displaced by each respective part, together they displace a volume equal to that displaced by the lungs. Hence, using the kinematic method provides physiologically-based information regarding lung volume events with utterance, in addition to information regarding the contribution of the component parts, RC and AB.

**Progress**—Instrumental acquisition and arrangement, subject selection, data acquisition, and analysis are in progress.

#### **Publications Resulting from This Research**

None reported.

### **[509] Characteristics of Tracheoesophageal Voice in Four Prosthetic Occlusion Conditions**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C499-RA)

**Purpose**—The purpose of this research is to compare the perceptual and acoustical characteristics of tracheoesophageal (TE) speech produced using four different prosthetic/occlusion combinations: 1) Blom-Singer duckbill prosthesis with digital occlusion of the tracheostoma; 2) Blom-Singer duckbill prosthesis with valve occlusion of the tracheostoma; 3) Blom-Singer low-pressure prosthesis and digital occlusion of the tracheostoma; and, 4) Blom-Singer low-pressure prosthesis and valve occlusion of the tracheostoma. Subject variables pertaining to medical/surgical histories (i.e., radiation therapy, radical neck dissection, myotomy, age, and primary or secondary surgery for TE puncture) will be

controlled in order to determine if these variables have any influence on the speaking characteristics of subjects.

**Progress**—To date, 25 tracheoesophageal speakers and 28 normal/laryngeal speakers have been recorded.

**Future Plans**—Statistical analyses will not be performed until the final year of this three-year study.

#### **Publications Resulting from This Research**

None reported.



## [510] Influence of Mode of Stimulation on Naming Performance in Aphasia

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Sponsor: VA Rehabilitation Research and Development Service (Pilot Project #C943-PA)

**Purpose**—The purpose of this study was to examine the influence of situational context (confrontation-naming versus running speech) on the recall of nouns and verbs by aphasic patients when the stimuli were videotaped, rather than depicted by line drawings, as in previous investigations.

**Results**—Forty-four aphasics were included in this investigation: 10 Broca's, 10 Wernicke's, 11 conduction, and 13 anomic. Four experimental tasks were completed: 1) confrontation-naming of 24 objects on videotape (single-word response required); 2) confrontation-naming of 12 actions on videotape (single-word response required); 3) naming the same 24 objects as in (1) in the context of running speech elicited via six videotaped scenarios; and, 4) naming the same 12 actions as in (2) in the context of running speech elicited via six videotaped scenarios.

A repeated measures-analysis of variance examining the effects of aphasia type, situational context (single word versus running speech), and grammatical class (noun versus verb) was performed. The obtained F ratios for the aphasia group, grammatical class, and situational context were significant. In addition to these main effects, a significant aphasia group/grammatical class interaction was obtained, as well as a significant interaction between situational context and grammatical class.

The interaction between aphasia group and grammatical class indicated that there were differences in performance between object- and action-naming, but that these differences were not parallel across the four syndromes of aphasia. Simple effects analysis revealed that, for Broca's and conduction aphasics, object-naming performance was significantly better than action-naming performance. Such a difference was not found for anomic and Wernicke's aphasics.

The interaction between situational context and grammatical class indicated that the differences in object- and action-naming performances also varied

according to whether patients were involved in the confrontation-naming or in the picture-description task. Specifically, when aphasics were considered as a unitary group (not divided into four syndromes), object-naming performance exceeded action-naming performance on the confrontation-naming task, but not on the picture-description task.

These results are most interesting when they are compared with findings of earlier investigations using line drawings. First, when using line drawings to examine object-naming, performance of Broca's and Wernicke's aphasics was systematically influenced by situational context. Such was not the case when using videotapes.

There was a significant interaction between situational context and grammatical form. Object-naming performance exceeded action-naming during confrontation-naming, but not during picture description.

Broca's and conduction aphasics performed significantly better when naming objects than when naming actions, while Wernicke's and anomic aphasics performed equally on the two grammatical forms. This is in contrast to previous studies with line drawings, wherein all four syndromes performed better when naming objects. The finding that anomic and Wernicke's action-naming performance is enhanced when actions are depicted in realistic form, is likely related to the underlying nature of their aphasias. These are the two syndromes that have been described as having a semantic deficit as the basis of their naming problems, with the connections and relationships among words being obscured. In contrast, Broca's and conduction aphasics have been described as having a motor-programming or phonological disruption as the basis of their naming impairment. Apparently, the realistic portrayal of actions of videotapes serves to enhance the target within the semantic network, thus facilitating performance of patients with a "semantic" deficit. Such portrayal does not, how-



ever, appear to facilitate those patients having a motor-programming or phonological breakdown underlying their anomias.

### [511] Perceptual and Acoustical Characteristics of Tracheoesophageal Voice

**Sarah E. Williams, PhD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Pilot Project #C941-PA)

**Purpose**—This study compared temporal and perceptual characteristics of tracheoesophageal (TE) voice produced in four different prosthetic/occlusion conditions: 1) using the Blom-Singer Duckbill Prosthesis and digital occlusion of the tracheostoma; 2) using the Blom-Singer Duckbill Prosthesis and valve occlusion of the tracheostoma; 3) using the Blom-Singer Low-Pressure Prosthesis and digital occlusion of the tracheostoma; and, 4) using the Blom-Singer Low-Pressure Prosthesis and valve occlusion of the tracheostoma.

**Methodology**—Characteristics of speech produced in each condition were compared to those of normal speech. Ten TE speakers and ten normal (laryngeal) speakers were included. Each speaker was video- and audio-taped. Temporal measures were made from amplitude-by-time tracings of Rainbow Passage readings and sustained /a/ productions. These measures included reading rate in words per minute, total pause time, percentage of total reading time occupied by pauses, total phrase time, number of words per phrase, and mean maximum phonation time for the vowel /a/.

For the perceptual portion of the study, five different judges, varying in their level of knowledge about alaryngeal voice, rated the speaking proficiencies of the laryngectomee and normal subjects by viewing the videotaped samples. The two "naive" judges were completely unfamiliar with laryngectomees. The two "informed" judges had been exposed to laryngectomees through coursework and lecture. Finally, the "expert" judge was a certified speech-language pathologist. Judges rated a number of speaking parameters for each laryngectomee speaking in the four prosthetic/occlusion conditions. The capacity of temporal

### Publications Resulting from This Research

None reported.

measures to discriminate among the four TE prosthetic/occlusion conditions and normals' speech was examined.

**Results**—Results revealed that the four TE prosthetic/occlusion conditions were discriminated from the normal speakers by two measures: 1) reading rate in words per minute; and, 2) mean maximum phonation time. Group means indicated that normals had a faster reading rate and a longer mean maximum phonation time than the TE speakers.

The four TE prosthetic/occlusion conditions were not discriminated among by any of the temporal measures. However, trends present in the means for the four prosthetic/occlusion conditions suggest that three temporal measures appeared to vary systematically among the conditions: 1) total pause time; 2) percentage of total reading time occupied by pauses; and, 3) mean maximum phonation time. These measures varied according to the presence/absence of the tracheostoma valve and not according to the use of the duckbill or the low-pressure prosthesis. Total pause time and percentage of total reading time occupied by pauses were both lower for the valve occlusion conditions, with mean maximum phonation time being longer for these conditions. These measures are all more similar to normal than the digital occlusion conditions.

When ratings made by the naive judges were analyzed, *extraneous speaking noise* was the only speaking parameter that discriminated among the speaking groups. Normals were rated the highest on this variable.

Within the TE prosthetic/occlusion conditions, low pressure and duckbill prostheses with valve occlusion were rated the highest on this parameter,



with low-pressure and duckbill prosthesis with digital occlusion rated the poorest.

When ratings made by the informed judges were analyzed, *visual presentation during speech*, and *extraneous speaking noise* discriminated among the groups. Again, normals were rated highest on both of these variables. For *visual presentation during speech*, duckbill/digital occlusion, low-pressure/valve occlusion, and low-pressure/digital occlusion conditions were rated approximately equally, with duckbill/valve occlusion given the worst rating. For *extraneous speaking noise*, low-pressure/digital occlusion was given the highest rating, followed by duckbill/digital occlusion, low-pressure/valve occlusion, and finally duckbill/valve occlusion.

When ratings made by the expert judge were analyzed, *extraneous speaking noise* was the only

variable that discriminated among the groups. Again, normals were rated the highest on this variable. Closely following normals' rating was low-pressure/digital occlusion. This was followed by duckbill/digital occlusion, low-pressure/valve occlusion, and duckbill/valve occlusion. This is the same rank order of prosthetic/occlusion conditions as found in the previous analysis with informed judges.

**Future Plans**—We will be working on a three-year investigation that will expand on this pilot study and will attempt to reduce the intersubject variability by grouping TE speakers into more homogeneous groups, based on their medical/surgical histories.

#### **Publications Resulting from This Research**

None reported.

### **[512] An Experimental Analysis of Response Elaboration Training in Aphasia**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C384-RA)

**Purpose**—Response Elaboration Training (RET) is a "loose training" procedure that was designed to increase the quantity and variety of content words produced by aphasic individuals during structured tasks and probes of nontraining settings and conditions. The emphasis in RET is on systematically shaping and chaining patient-initiated utterances into increasingly longer and more elaborate responses. The key experimental questions for this project are: 1) Will RET facilitate an increase in the amount of information (i.e., number of content words) produced by patients with Broca's aphasia?; 2) Will subjects generalize improvements in verbal elaboration skills to nontraining stimuli, settings, and individuals?; and, 3) What is the relative efficacy of RET as compared to a didactic treatment approach?

**Methodology**—A multiple baseline across behaviors design that incorporated a multiple probe component was used to examine the effectiveness and generality of RET. In addition, descriptive analyses

were developed to examine qualitative aspects of patient response and social validation. A combined alternating treatments/multiple baseline design is being used to explore the relative efficacy of RET and didactic treatment.

**Results**—Extensive time series data have been collected and analyzed for 15 aphasic patients and social validation data have been obtained for 10 matched normals. This study was primarily concerned with the acquisition and generalization of improved verbal elaboration skills for Broca's aphasic patients. Results for five chronic Broca's patients have demonstrated that RET facilitated a clinically significant increase in the number of content words produced on training and generalization stimuli. Although across-patient variability has been evident, some degree of generalization of training effects to setting and individuals has also occurred. Follow-up data indicate that Broca's patients have generally maintained improvements on clinical probes over time. Descriptive analyses of



probe data also revealed that the efficiency of verbal production remains relatively stable as the number of content words increases during RET. There was also a clinically significant increase in the number of *novel* content words produced on performance probes over time.

Results for three fluent aphasic patients replicated our findings for the Broca's patients. That is, the fluent subjects showed rapid and stable gains in the number of content words produced in response to training and generalization stimuli following RET. Relatedly, they also exhibited a significant degree of generalization to untrained setting, individuals, and situations. Improvements were maintained for treatment and spontaneous generalization conditions over time.

In an attempt to further examine the efficacy of RET, intervention was initiated to facilitate acquisition of an elaborate drawing system as a means of functional communication for two nonverbal aphasic apraxic subjects. Both subjects acquired the ability to spontaneously produce elaborate drawings in response to training stimuli and functional generalization probes. These results were subsequently replicated with another subject who acquired use of a computerized symbol system as an augmentative means of communication.

Finally, we have obtained preliminary data on 4 patients comparing the relative efficacy of RET and a didactic treatment approach that limits patients'

response options to preselected lexical items. The preliminary nature of these findings does not yet permit firm conclusions regarding the relative effectiveness of these disparate treatment approaches.

**Future Plans**—We plan to continue our efforts to compare RET with more didactic treatment approaches and evaluate the effectiveness of the program with a wide range of aphasic patients. In addition, we plan to develop computerized analogues of RET so that we can objectively evaluate the relative contributions of stimulus and response variables that contribute to the effectiveness of this and other "loose training" procedures. Our overall goal remains the examination of factors that facilitate generalized responding in aphasia.

#### Publications Resulting from This Research

**The Generalization of Response Elaboration Training Effects.** Kearns KP, Potechin-Scher G, in *Clinical Aphasiology Conference Proceedings*, T. Prescott (Ed.), San Diego: College-Hill Press, 1988.

**Methodologies for Studying Generalization.** Kearns KP, in *Generalization Strategies in Communication Disorders*, J. Spradlin, L.V. McReynolds (Eds.), Toronto, Canada: B.C. Decker, Inc., 1989.

**A Qualitative Analysis of Response Elaboration Training Effects.** Gaddie A, Kearns KP, Yedor K, in *Clinical Aphasiology Conference Proceedings*, T.E. Prescott (Ed.), San Diego: College-Hill Press (in press).

**Broca's Aphasia.** Kearns KP, in *Aphasia and Related Neurogenic Language Disorders*, L.L. LaPointe (Ed.), New York: Thieme, Inc. (in press).

### [513] Promoting Generalized Language Use: An Analysis of Treatment/Subject Variables

**Patrick J. Doyle, PhD**

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**Sponsor:** VA Rehabilitation Research and Development Service (Project #C330-2RA)

**Purpose**—This project is a continuation of our ongoing program of research. The program's purpose is to develop a treatment technology that will enhance generalized functional communication skills in adults with acquired neurogenic speech and language disorders.

**Methodology**—Single-subject experimental designs with replication across subjects and behaviors have been employed to study the generalization effects of

treatment. The primary dependent variables studied have included the communicative functions of requesting information, making personal statements of fact, and responding to verbal queries. Behavioral change is measured over time in the context of conversational interactions between familiar and unfamiliar conversational participants. Social validation procedures are also employed to supplement quantitative measures.



**Progress**—Studies to date have been conducted with non-fluent aphasic subjects resulting in the identification of a number of treatment variables found to be functionally related to the generalization effects of treatment. These variables included the use of multiple trainers, social reinforcers, functional response criteria, and reinforcement of subject-initiated utterances. The effects of these variables have been replicated across four behaviors in twelve subjects.

**Future Plans**—The next phase of our program will examine the effects of setting events (i.e., familiarity of conversational partners, the number of conversational participants, and clinical versus home environments) on the use of a variety of speech and language behaviors in both aphasic subjects and normal controls. This study will address questions regarding: 1) the effects of measurement contexts on performance; 2) other behaviors that may require intervention; and, 3) the social validity of treatment effects.

Following this phase, experimental studies will be conducted to provide additional direct and

systematic replications of the effects of treatment across a variety of target behaviors, subjects, and measurement contexts. These studies will address the generality or external validity of treatment effects.

In the final phase of the project, we will examine the relationship between generalization scores and selected subject variables including severity of aphasia, severity of apraxia of speech, severity of word retrieval deficit, severity of auditory comprehension deficit, and premorbid personality variables. This investigation will also address questions regarding treatment candidacy.

### Publications Resulting from This Research

**Facilitating Generalized Requesting Behaviors in Broca's Aphasia: An Experimental Analysis of a Generalization Training Procedure.** Doyle PJ, Goldstein H, Bourgeois MS, Nakles KO, *J Appl Behav Anal*, 22:157-170, 1989.

**Experimental Analysis of Syntax Training in Broca's Aphasia: A Generalization and Social Validation Study.** Doyle PJ, Goldstein H, Bourgeois M, *J Speech Hear Disord* 52:143-155, 1987.

**Facilitating Functional Conversational Skills in Aphasia: An Experimental Analysis of a Generalization Training Procedure.** Doyle PJ, Nakles KO, Goldstein H, *Clin Aphasiol* (in press).

## [514] Computer Use by Aphasic Individuals

**Katherine H. Odell, MS; Michael J. Collins, PhD; Charles C. Lee, MS; Jay Hinkens, BS**

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**Sponsor:** National Institute on Disability and Rehabilitation Research

**Purpose**—A number of studies are being conducted to examine the reaction and performance of individuals with aphasia in operating certain computer interfaces. These studies are currently examining the use of certain interfaces in standard tests administered to individuals with aphasia; however, they also have implications in understanding general cognitive issues in computer access.

**Methodology**—This project involves a series of studies. The first study examines the relative efficiency with which aphasic adults use different computer input systems (i.e., keyboard, long range light pen, stylus, touch-sensitive screen, and joystick). Performance on a measure of reading comprehension is compared across all interface systems. The reading measure for this project is a

multiple choice synonym identification test, with two levels of difficulty. A different test was developed for each interface system; all tests were designed to be equivalent in grade level. Algorithms for scoring and response time data collection were devised.

A second study in the series will investigate computer strategies for recognizing perseveration and self-correction attempts and will develop software to both interrupt perseveration and facilitate self-correction tendencies. The behavioral tool for this study is a computerized version of the Revised Token Test (McNeil and Prescott, 1978), a measure of auditory comprehension on which aphasic subjects are likely to display perseveration or self-correction tendencies.

**Progress—Study 1.** Subjects have been tested, and data collection is currently being wrapped up.

**Study 2.** The software routine developed for the Revised Token Test has been completed. Programming algorithms for perseveration interruption and self-correction facilitation are being completed. Preliminary testing of software with 10 normal subjects has been completed and revisions made.

**Results/Implications—**Results of this work will assist in the selection of appropriate input systems for

aphasic users. Further, analysis of response characteristics using each of the interface systems will address the theoretical question of competition for cognitive resources; i.e., the degree of cognitive ability required of aphasic users to both operate the device and proceed with the test.

#### **Publications Resulting from This Research**

None reported.

### **[515] Signal Processing Device for Impaired Speech Assessment**

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**Sponsor:** *National Institute of Child Health and Human Development, National Institutes of Health*

**Purpose—**The effectiveness of speech therapy and training is limited by the time available for interaction between the therapist or teacher and the pupil. A device that could automatically compare a brief utterance to a standard or reference version of that utterance, and display a measure of the trial utterance on a speech-quality scale, would serve as an important extension of speech therapy and training between lessons. Research into the nature of

speech and the rapid development of signal processing technology now permit construction of such a device at reasonable cost. The feasibility of applying phoneme-based speech recognition algorithms to the evaluation of impaired speech will be determined.

#### **Publications Resulting from This Research**

None reported.

## **D. Deaf-Blind**

### **[516] A Voice-Output Questionnaire Administrator**

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**Sponsor:** *VA Rehabilitation Research and Development Center Core Funds; VA Western Blind Research and Development Center*

**Purpose—**This project employs a computer-controlled DECtalk speech synthesizer to administer, score, display the results of, and maintain data from Profile of Mood States (POMS), a standard psychological test for visually impaired and blind individuals.

**Methodology—**In order to measure and compare the mental state of individuals, the bipolar form of

POMS has been developed by the Educational and Industrial Testing Service to quantify six selected bipolar subjective-mood states. In this test, each mood consists of two extremes: one is represented by the positive aspects of the mood, and the other by the negative aspects (such as happy-sad). Each of the six moods (composed-anxious, agreeable-hostile, elated-depressed, confident-unsure, energetic-tired, and clearheaded-confused) are measured by analyz-



ing the test taker's level of agreement to positive and negative mood indicator phrases such as "cheerful" or "downhearted."

Although POMS was developed to evaluate established mood states and feelings reported by both normal and psychiatric patients, the principal contemplated use of this test at the Western Blind Rehabilitation Center (WBRC) is to evaluate the relative effectiveness of various training programs in reducing negative moods while enhancing the positive ones.

The POMS test cannot be administered in the traditional manner to patients who are blind or have visual impairments because neither group has the visual acuity to read the individual phrases, nor the ability to indicate their choice on the answer sheet. Currently, a staff member reads the phrases to subjects, queries for a response, and fills in the appropriate box on the answer sheet. Later, answers are hand scored and a profile produced.

Although the time for a sighted person to take the test is only 5 minutes, the staff time required to administer the test to a WBRC inpatient is often doubled or tripled.

In addition, the current manual method of scoring and graphing results is time consuming. Other staff duties often interfere with these tasks, so the motivation exists to reduce the number of these tests given, rather than to increase their administration during the patients' course of therapy and training. The whole process is labor intensive: it requires administering, scoring, and graphing results.

The prototype system consists of an IBM XT compatible computer with printer, a DECtalk speech synthesizer, and appropriate software. The DECtalk unit was chosen because it produces speech that is readily understood by those who have no computer experience.

During test-taking using the DECtalk, the software first provides verbal instructions to the patient and then starts the test. Each mood phrase is presented in turn and a response is solicited. Responses are made by the patient either pressing a key on a standard keyboard or one of a set of switches. If, after a given time, no answer is

received, the computer reissues the phrase. All patient responses are confirmed, and can be changed if a mistake is made.

At the completion of the test, the computer performs all the necessary scoring, collating, and computing required to produce a dated graph of the mood-state profile. This result is then compared to others taken previously and is eventually placed in the patient's medical record.

**Preliminary Results**—Eighteen normally sighted and 18 visually-impaired persons able to read with optical aids participated in the evaluation of the DECtalk system using the POMS. The study was designed so that subjects took the POMS test three times during an hour. The subjects were asked to use the DECtalk system, take the written version, and have the POMS read by an individual. The order of administration was counter-balanced. Valuable feedback obtained from the participants can be used to improve the original system.

Analysis of variance tests showed that the order and mode of testing did not have a significant effect. Half of the visually-impaired subjects preferred the DECtalk system to the other two methods of test administration.

**Future Plans/Implications**—The final phase involves expansion of the system to be used with other tests and the development of an authoring program to be used with follow-up questionnaires related to the WBRC program.

Two positive results are anticipated upon completion of the project. First, the project will provide the WBRC with needed data concerning the effect of the courses and therapy it provides to its patients. Second, it will provide information on the utility of computer-based speech synthesizers in administering psychological tests to visually impaired and blind individuals. This data should also prove useful in the development of other systems that disseminate information to callers in a similar manner.

#### **Publications Resulting from This Research**

**DECtalk Test/Questionnaire Administration Project.** McKinley J, *WBRC 1989 Research Summary*, Palo Alto, CA, 1989.



## [517] A Second Generation Mechanical Hand Communication Aid for the Deaf-Blind

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Rehabilitation Research and Development Center, VA Medical Center, Palo Alto, CA 94304

Sponsor: *VA Rehabilitation Research and Development Center Core Funds; The Smith-Kettlewell Eye Research Institute*

**Purpose**—People who are both deaf and blind experience extreme social and informational isolation. Those deaf-blind individuals who use a tactile version of fingerspelling and/or sign language to converse with others enjoy some relief from this isolation. This tactile method is far from ideal, however, as it restricts interaction to others who are both knowledgeable in sign language and willing to engage in this hands-on-hands communication technique. The problem is further exacerbated by fatigue caused by this system of information exchange.

A potential solution to this problem is offered by Dexter II, a second-generation computer-based electro-mechanical fingerspelling hand. This device enables a deaf-blind user to receive tactile messages from the mechanical hand in response to keyboard input during person-to-person communication, as well as gain access to computer-based information.

**Methodology**—In 1985, the Rehabilitation Engineering Center of The Smith-Kettlewell Eye Research Institute sponsored a class project in the Department of Mechanical Engineering at Stanford University in which four graduate students designed and fabricated a mechanical fingerspelling hand. A major goal was to develop a system with easily modifiable finger positions. This quality was realized in the completed project, a new robotic fingerspelling hand named "Dexter."

A more compact version of the mechanical system was designed in Spring 1988 by three graduate mechanical engineering students at Stanford University. Their design, Dexter II, employs DC servo motors to pull the finger drive cables of a redesigned hand, thereby eliminating the need for the pneumatic power source. A speed of approximately four letters per second (almost twice that of the first design) can be achieved with the improved device.

In the original version, the microcomputer and associated software control the opening and closing of a bank of valves that direct air pressure to

specific pneumatic cylinders, while the DC servo motors in Dexter II are controlled by pulse-width modulation chips. In both cases, the resultant motion pulls on the drive cables which are the "tendons" of the fingers.

In operation, a message is typed on a keyboard (an Epson HX-20) by an able-bodied person. The ASCII value of each letter is used by the software as a pointer into an array of stored control values. Two to six of these control operations, each separated by a programmed pause, are needed to specify the finger movements corresponding to a single letter.

Although neither Dexter nor Dexter II can exactly mimic the human hand in fingerspelling all the letters (such as the special wrist and arm motions required in J and Z), they can display modifications which resemble those enough to make them easy to learn by the deaf-blind user.

**Results**—Deaf-blind clients of Lions Blind Center (Oakland, CA) were subjects for the initial testing of Dexter. They identified most of the letters presented by the robotic hand without any instructions, and in less than an hour were correctly interpreting sentences. Equally important was their positive emotional reaction to the hand. They seemed to really enjoy using it and were intrigued by its novelty. No negative comments were made concerning its mechanical nature or any other aspect of the system.

Dexter II was first tested by a deaf-blind person who is extremely proficient at receiving tactile fingerspelling. This subject provided many suggestions for improving Dexter II's letter shape configurations. Subsequently, it was introduced to twelve deaf-blind people during their annual retreat. About twenty deaf-blind attendees at the annual Deaf-Blind Conference in Colorado Springs in June 1989 had a chance to experience Dexter II. The device was also exhibited at the RESNA '89 Conference in New Orleans and at the InvenTech meeting in Anaheim in September 1989. The deaf-blind individual's ability to initially understand Dexter II varied



considerably, and long-term evaluations have been planned.

**Future Plans/Implications**—Additional testing will be conducted on the ability of deaf-blind people to use the mechanical hand for extended periods of time, as well as on additional refinements of the configurations for the letters, and optimum rate of letter presentation.

Dexter is intended to serve deaf-blind users as a complete receptive communication system, not just as a means of receiving information in face-to-face situations. Its ability to respond to computer input means it can be interfaced to a telecommunications device for the deaf (TDD) to provide deaf-blind people with telephone communication. It can also be

connected to computers to provide expanded vocational and avocational potential to the deaf-blind community.

#### **Publications Resulting from This Research**

**A Robotic Hand as a Communication Aid for the Deaf-Blind.** Gilden D, in *Proceedings of the 20th Hawaii International Conference on System Sciences*, 1987.

**Spelling in Hands.** Gilden D, Jaffe DL, *SOMA*, 1987.

**Dexter II: The Next Generation Fingerspelling Hand for Deaf-Blind Persons.** Jaffe DL, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 349-350, 1989.

**Second-Hand Information for Deaf-Blind Individuals.** Gilden D, in *Proceedings of the Conference on Computer Technology and Persons with Disabilities*, California State University, Northridge, CA (in press).

### **[518] Transparent Access to Sources of Computer-Based Information**

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**Sponsor:** VA Rehabilitation Research and Development Center Core Funds; Digital Equipment Corporation

**Purpose**—The purpose of this study was to develop a software program, KIOSK, that demonstrates how the barriers to obtaining computer-based information can be reduced, thus benefiting both able-bodied and disabled people.

**Methodology**—The KIOSK software has been designed to run on microcomputer systems. A DECtalk speech synthesizer completes the hardware system and provides a friendly interface between the computer, data, and individuals requesting information.

In operation, the user accesses a home or business touch-tone telephone to dial the telephone number of the DECtalk speech synthesizer. The equipment answers the telephone and KIOSK then mediates the interaction between the caller and the computer. The software: 1) permits the DECtalk to speak computer-based text files; 2) receives data from the DECtalk on which touch-tone keys are pressed by the caller; and, 3) works with knowledge of a structure for presenting the text files.

In the current implementation, the interaction between the caller and the computer is accomplished

through a series of computer-initiated speech output and caller responses. The user is presented with either instructions, information, or choices. The caller's response to a choice is made by pressing the touch-tone key corresponding to a selection. The DECtalk recognizes the keypress and causes the program branches in an appropriate manner based upon the response. This process is continued, with the computer sending information from text files to the DECtalk which is spoken over the telephone and the user then makes choices as to how the interaction is to proceed. For example, a typical choice might be: Press 1 for information on recreational devices; Press 2 for information on robotic applications; or, Press 3 for information on new wheelchair developments.

KIOSK has been developed as a general-purpose program. It operates by structuring disk-based text files, and verbally presents them to the caller at the proper time, after the right sequence of choices has been made. The information provider designs this structure and provides the text files to be spoken by the program. As such, KIOSK is a flexible authoring system for the DECtalk speech synthesizer



and can be used to disseminate a variety of information.

**Preliminary Results**—One current application demonstrated at this facility is a voice output version of this Center's 1988 Progress Reports, which are descriptions of the operation of this Center and its projects.

When called, the system welcomes the user and briefly describes its operation. The caller is first asked to press any touch-tone key to continue and subsequently asked to press the 0 key. After a short introduction to the Center, the user is asked to choose one of the three groups (Orthopaedic Biomechanics, Neuromuscular Systems, or Human-Machine Interface) within the Center. The user responds with a touch-tone keypress and the program branches to the information and projects of the chosen group. The title of a project is then presented and the caller is given the choice of whether to hear the text of the project, go on to the next project, or return to the previous menu of choices.

An unexplored application of KIOSK is the voice output dissemination of general consumer-type information that would normally be presented in a traditional printed newsletter format.

**Future Plans/Implications**—KIOSK makes it possible for individuals without access to or knowledge of computers to obtain computer-based information. Information requesters simply employ their touch-tone telephone, a device already in their home

or business, and one which they already know how to use. The substantial barriers of having to buy and learn how use a computer for obtaining computer-based information are eliminated. Visually-impaired people could benefit from this type of access, and it serves able-bodied individuals equally well.

In addition, modem communication could be added to supply the same information to people who have computer systems, including hearing-impaired individuals. In summary, a system based on KIOSK serves persons who are disabled because of lack of information or lack of funds and motivation to buy and learn how to use a computer to access sources of computer-based information.

The next major extension of this work will allow a computer system to mediate the exchange of information between the caller and the information contained in a remote database such as CompuServe or computer-based bulletin boards systems. This would be accomplished by first engaging in a dialog with the caller to determine the information required and then connecting to the appropriate information source. Next, the computer would send the required commands in the proper syntax to obtain information from a remote system and present it to the user as synthesized speech. An electronic librarian would thus be created to transparently search multiple databases of electronic information for the caller.

#### **Publications Resulting from This Research**

**Transparent Access to Sources of Computer-Based Rehabilitation Information.** Jaffe DL, in *Proceedings, ICAART 88*, Montreal, 394-395, 1988.

### **[519] Application of Technological Devices for the Enhancement of Cognitive Performance and Communication in Prelingual Deaf-Blind Children**

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**Sponsor:** Office of Special Education Programs, Department of Education

**Purpose**—The primary purpose of this project is to demonstrate specific procedures for meeting the complex communication needs of prelingual, profoundly deaf-blind children via the development of intervention tools/techniques, and the adaptation or development of technological signaling devices. An emphasis has been placed on the development of

signaling systems that allow the child to request and make appropriate responses to the requests of others. The signaling devices are viewed as a means to the eventual initiation of more complex cognitive and communicative behaviors by the deaf-blind child. The devices fabricated as part of this project provide a bridge between the deaf-blind child and



his/her communication partners. This allows the child to exercise some degree of control and to grow in both self-esteem and awareness of the near and distant environment. The child is thus empowered to initiate communication and respond to the communicative attempts of others.

**Progress**—Since the project's inception in September 1987, several signaling systems have been fabricated. Some of the commercial devices purchased, tried, and modified for this population include the Tacticon 1600, Tactaid II, and Mini-Fonator. The Mini-Fonator tactual signaling device has undergone a third adaptation effort (a wireless microphone link) in order to eliminate extraneous wires and to limit ambient noise and vibrations pick-up.

Other accomplishments include an adapted trampoline to encourage both exercise and communicative dyad. A child's walker was instrumented to produce music when the desired direction, distance, and rate of travel occurred. A commercial toy named "Simon" has been modified to produce tactile vibrations in addition to light and sound outputs. The modified Simon now flashes and vibrates with increasingly lengthier patterns of vibrations at its four panels. When a child is able to replicate this pattern by depressing the corresponding panels, an auditory reward is given. Other multisensory and motivational toys (fan, radio, and a musical bear) have been purchased for use in various intervention strategies under development. Again, these devices support the goal of independent cause-effect behavior.

To aid the teaching of proper sequencing and task completion concepts, several portable table tops

of various sizes have been made to interface with an assortment of switches. These switches (self-time, latched, and/or simultaneously activated) can be used to provide rewards of music and vibrations upon proper sequencing.

Other project activities include a swimming and gymnastic program during the summer. The program was designed to facilitate independent mobility and enhance communication in highly motivational non-classroom types of setting. Two clients in 1988 and four in 1989 have participated in this program. Their progress in achieving improved mobility and communication skills has been very encouraging.

**Future Plans**—Future plans for this project include: a third summer of the swimming and gymnastics program; addition of motor sounds to an exercise bicycle and arm ergometer to encourage exercise and promote physical development in deaf-blind children; addition of music and kinesthetic vibrations to various mobility aids as a reward for appropriate behavior; field tests of several signaling devices in school settings; analysis of client progress; evaluation of various intervention strategies tried; and preparation and dissemination of brochures and videotapes that describe the project's findings.

#### **Publications Resulting from This Research**

**Technological Devices for Deaf-Blind Children: Needs and Potential Impact.** Szeto AYJ, Christensen KM, *IEEE Eng Med Biol Mag* 7(3):25-29, 1988.

**A Piagetian Model for Observation of Verbal, Nonvocal, and Nonverbal Cognitive Behavior,** in *Cognition, Education and Deafness—Vol. II*, Christensen KM, Washington, DC: Gallaudet University Press, 1990.

## XVI. Cancer

### [520] Cricopharyngeal Myotomy Study

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**Purpose**—This study will attempt to answer on a prospective basis whether performance of a cricopharyngeal myotomy improves swallowing. This surgical procedure has been purported to improve dysphagia from a variety of illnesses.

**Progress**—A multi-institutional 5-year trial has been started. The subjects for this trial are patients with squamous cell carcinoma involving the supraglottic larynx and base of tongue sites. This population is

anticipated to suffer with dysphagia following standard treatment. The randomization is between performance of the cricopharyngeal myotomy versus no myotomy. The primary method of evaluation is videofluoroscopy utilizing a variety of barium content substances. Patient enrollment in this study began on April 1, 1989.

#### **Publications Resulting from This Research**

None reported.

### [521] Performance Status Scale for Head and Neck Cancer Patients

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**Sponsor:** *National Cancer Institute, National Institutes of Health*

**Purpose**—Head and neck cancer patients face unique and significant disturbances in speech, eating, and social functioning. Currently these disabilities are not measured in any systematic way. The traditional instrument, the Karnofsky, while providing a global assessment, does not address these specific areas of function. The goal of the current research project was to develop and test the reliability and validity of a new measure, the Performance Status Scale for Head and Neck Cancer Patients. The aim was to design a simple, practical assessment instrument with which to evaluate the unique areas of dysfunction experienced by head and neck patients.

**Methodology**—The new instrument is clinician rated and consists of three subscales: 1) normalcy of diet; 2) eating in public; and, 3) understandability of speech. In each subscale, a list of appropriate items

is arranged hierarchically to describe a continuum, with total incapacitation at one end, to full, normal functioning at the other. Patients receive a total of three ratings, one on each subscale.

Performance ratings have been obtained on a group of 200 head and neck patients. Of this group, 200 were retested, and approximately 20 percent were simultaneously rated by two members of the research team. In addition, to enable assessment of the degree to which the scale is specific to head and neck patients, a comparison group of 30 breast cancer patients was also evaluated.

**Results**—Results indicated that the Performance Status Scale for Head and Neck Cancer Patients can be used reliably by different raters. Kappa statistics testing intrarater agreement between members of the research team indicated substantial strength of agreement.



The three subscales were designed to measure separate areas of functioning. Correlational analyses demonstrated that each subscale does assess a unique function and adds independent information to that provided by the Karnofsky. Ratings on the new scale also appear to accurately describe, and discriminate, functional differences not detected by the Karnofsky. For example, scale ratings were significantly different by type of surgery, with differences in the expected directions. Finally, as designed, the measure was found to be specific to head and neck patients as compared to a group of breast cancer patients.

**Implications**—These findings demonstrate that the new instrument is a useful and effective tool for evaluating and monitoring the areas of functioning critical to the performance of head and neck cancer

patients. Ratings on the Performance Status Scale for Head and Neck Cancer Patients may be used in planning rehabilitation programs and in determining eligibility for and outcome of clinical trials.

**Future Plans**—Future research endeavors include longitudinal studies, that is, repeated administration of the scale from diagnosis through various phases of illness, treatment and rehabilitation.

#### Publications Resulting from This Research

##### Performance Parameters in Head and Neck Cancer Patients.

Lansky SB, List MA, Ritter-Sterr C, Logemann J, Willis M, in *Proceedings of the American Society of Clinical Oncology* (Abstract), New Orleans, LA, 1988.

**Quality of Life in Head and Neck Cancer Survivors.** Lansky SB, List MA, Ritter-Sterr C, Logemann J, Pecis K, in *Proceedings of the American Society of Clinical Oncology* (Abstract), San Francisco, CA, 1989.

## [522] Effects of Cancer Chemotherapy on Dietary Habits

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**Sponsor:** National Cancer Institute, National Institutes of Health

**Purpose**—Learned food aversions (LFA), aversions which form toward foods after their ingestion, have been associated with illness and are common in cancer patients, though they remain poorly characterized. The purpose of this project is to explore: 1) the incidence of LFA in patients receiving either chemotherapy or radiotherapy; 2) common food targets; 3) the critical period for LFA formation; 4) LFA persistence; 5) clinical consequences of LFA; and, 6) methods to ameliorate the problem.

**Methodology**—Radiotherapy patients are assessed prior to the initiation of therapy, every other day for the first week, weekly for the next 5 weeks, and at 2, 4, and 6 months. Chemotherapy patients are evaluated before treatment and at 1, 2, 4, and 6 months following the start of therapy. LFA are documented by open-ended questionnaires, acceptability ratings for foods ingested in the 48-hour period surrounding the first treatment day, and a food intake procedure. An interference procedure is used in an attempt to divert LFA away from nutritious foods and toward items of little nutritional consequence

for the patient. Two-thirds of the subjects are requested to ingest items of varying sensory and nutrient composition prior to treatment so that these “scapegoat” items may be targeted for the aversion instead of items in the patient’s customary diet.

**Progress**—To date, 53 patients have been recruited. Thirty-two were administered radiotherapy and 17 were chemotherapy patients. Four patients were recruited but dropped from the study due to death (n = 1) or failure to return to the hospital after only the initial evaluation (n = 3).

**Preliminary Results**—Preliminary analyses on the radiotherapy patients has revealed an incidence of LFA of 50 percent. This is comparable to the incidence noted in the chemotherapy patients studied in the first part of this research project. Secondly, foods representing all common food groups have been targeted, although certain foods appear to be particularly problematic: sweets, meats, high fat foods, and especially grain products. This last item was not found to be a common target



in chemotherapy patients. Third, among those patients forming aversions, the mean number of items targeted was 3.3. Thus, the aversions appear to be very specific. In addition, they tend to be transient, lasting only from 1 to 2 months. Fourth, foods ingested as much as 24 hours before or following the first course of therapy can be targeted for an aversion. Thus, there is a wide window for aversion formation and the strategy of withholding food around the time of treatment in order to avoid the problem will not be practical. Fifth, there is presently no evidence that radiotherapy patients who form food aversions experience a higher incidence of loss of appetite or body weight. They also do not display a different pattern of disease progression than patients not forming aversions. Thus, as was the case with the chemotherapy patients, learned

food aversions may pose their greatest threat to the quality of life. Sixth, radiation patients with a prior history of food aversions are more than twice as likely to form new aversions subsequent to the initiation of therapy relative to those with a negative prior history.

The issue of whether or not there may be a genetic component to food aversion learning was explored by collecting food aversion data from 60 families. These data are currently being analyzed.

#### **Publications Resulting from This Research**

**Learned Food Aversions Among Cancer Chemotherapy Patients: Incidence, Nature and Clinical Implications.** Mattes RD, Arnold C, Boraas M, *Cancer* 60:2576-2581, 1987.

**Management of Learned Food Aversions in Cancer Chemotherapy Patients Receiving Chemotherapy.** Mattes RD, Arnold C, Boraas M, *Cancer Treat Rep* 71:1071-1078, 1987.

### **[523] A Study of Cancer Treatment Patients' Concrete Service Needs**

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**Sponsor:** *National Cancer Institute, National Institutes of Health*

**Purpose**—Many cancer patients develop a need for concrete (daily living) services at some point in the course of their disease. If these needs are not met, overall functioning and quality of life may be compromised. However, negotiating the complex medical care and social service systems in search of assistance may pose difficulties for patients and families who are already burdened by the disease experience. The overall goal of this study is to describe the prevalence of concrete service needs among patients receiving chemotherapy and to implement and evaluate a short-term, educationally-oriented case management intervention designed to empower patients and their families in process of service acquisition.

**Methodology**—The study was conducted in two phases. During Phase 1, a survey designed to identify concrete service needs was administered to 413 patients in active chemotherapy treatment at participating clinics/offices. A 12-month follow-up interview was administered to patients with metastatic disease at the time of the initial interview.

Disease and treatment-related information was abstracted from patients' medical records. A 22-item screening instrument was designed based on analysis of interview and medical record abstract data.

Patients were identified for Phase 2 of the study at two cancer treatment centers and the office of nine private physicians. Consenting patients were administered the risk assessment instrument developed in Phase 1, as well as assessment of physical functioning, social support, service utilizations, and quality of life. Patients completing the initial interview were randomized into intervention and control groups. Follow-up interviews were administered at 3- and 6-months post-baseline. Patients randomized into the intervention group were visited by a case manager, and an oncology nurse, shortly after the initial interview. For each need identified by the case manager in the course of her visit, a specific intervention plan was formulated. Educational and service information was distributed at this visit. Following the initial visit, patients were phoned at 2-week intervals to assess new situations requiring intervention and evaluation, and redirection for



resolution of previously identified problems. A visit was scheduled at the end of the 3-month intervention to allow the case manager to assess the independence of the patient in securing needed services.

Phase 2 was completed in July, 1989. Data analyses and report preparation are currently underway.

**Preliminary Results**—Patients in the control and experimental groups (N=225) were similar on all baseline measures. The mean age of patients was 57 years old and 69 percent were married. Slightly more than 63 percent of the total sample were females and 69 percent were married. The intent of cancer treatment was palliative in 62 percent of the cases and the treatment was by multiple agent chemotherapy for 75 percent of the patients.

Analysis of the process of the intervention indicates that the majority of the intervention sample (80 percent) received two visits by the case manager, and the average length of each visit was 80 minutes. Nearly three-quarters of patients (73 percent) received 4-6 telephone calls by the case manager in the course of the 3-month intervention.

In contrast, the vast majority of patients (88 percent) did not make use of the opportunity to initiate calls to the case manager.

Preliminary findings based on the 3-month outcomes reveal low rates of unmet needs among both the control and the experimental groups. The level of symptom severity between the control and experimental groups was also similar. Final results based on the 6-month outcomes will stress the experiences of the case manager in educating the experimental group regarding self-initiated symptom reduction and exchanges with the formal care system.

#### **Publications Resulting from This Research**

**Cancer Patients' Quality of Life Over the Disease Course: Lessons from the Real World.** Mor V, *J Chronic Dis* 40(6):535-544, 1987.

**Work Loss, Insurance Coverage, and Financial Burden Among Cancer Patients.** Mor V, in *Proceedings of the Workshop on Employment Insurance and the Patient with Cancer*, 1987.

**The Role of Concrete Services in Cancer Care.** Mor V, Guadagnoli E, Wool M, *Adv Psychosom Med* 18:102-118, 1988.

**Negotiating Concrete Needs: Short-Term Training for High Risk Cancer Patients.** Wool MS, Guadagnoli E, Thomas M, Mor V, *Health Soc Work*, August, 1989.

### **[524] Cancer Patients' Home Care Needs and Costs**

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**Purposes**—The increasing prevalence of cancer patients under treatment and the trend toward “dehospitalization” of care will lead to more people receiving care outside of the protective environment of the hospital. How patients are affected by this trend and how well the community support system meets the demands of these patients is an important issue for the present and future. Need for assistance in performing physical care (e.g., bathing, eating, toileting), instrumental activities (e.g., shopping, cooking), and/or administrative activities (e.g., filling out forms, handling finances) in the home setting arises as a consequence of disease-induced and treatment-related symptomatology, as well as general physical decline.

The overall goal of this project is to describe and analyze the home care needs and services used by cancer patients with nonlocalized cancer who are initiating chemotherapy or radiation therapy in three different areas of the northeastern United States (Rhode Island, New York City, central Pennsylvania). Additionally, we will describe the extent of emotional and socioeconomic burden experienced by families providing care to patients, and how the prevalence and intensity of burden changes in relation to disease progression and anti-tumor treatments.

Eligible cases are those patients aged 21 or older with nonlocalized, recurrent, or nonresectable disease whose primary disease sites involve solid tu-



mors of the gastrointestinal tract, genitourinary area, breast, lung (all stages), and head and neck, and who are initiating radiation or chemotherapy treatment at the clinic or private practice of participating physicians at the three study sites.

**Methodology**—Patients were interviewed at baseline, defined as within 30 days of identification at participating clinics/offices, and were randomized into follow-up interview samples occurring at either 3- or 6-months post-baseline. Caregivers were interviewed at both baseline and follow-up within 2 weeks of the time designated for their associated patient. All interviews took place over the telephone. A Financial/Service Diary was employed with a random half of the sample to obtain detailed information regarding out-of-pocket cost of illness and service utilization within a specific 2-week time period. In addition to the interviews, disease and treatment-related data was abstracted from physician records following a 6-month follow-up period for each patient.

**Preliminary Results**—The data collection phase of the project was completed in August, 1989 and data analysis is underway. A total of 1,009 eligible patients were identified, and baseline interviews were completed with 633 (62.7 percent) of these patients. Interviews were also obtained from 485 of the patients' primary informal caregivers. Slightly more than half (53.8 percent) of the patient sample is female, and less than half (42.5 percent) are age

65 or older. The vast majority of the sample has nonlocalized disease (93.1 percent). The major cancer types comprise the majority of the sample (lung, 22.2 percent; breast 23.4 percent; colorectal, 15.8 percent).

Preliminary cross-sectional analyses indicate that similar proportions of the sample have a need for assistance with personal care such as bathing and transferring (14.2 percent), and for assistance with medical care tasks (11.5 percent). Need for assistance with instrumental tasks such as housework, shopping, and cooking is much higher (91.2 percent), although when adjusted for role-related explanations (i.e., "he/she has always helped me with this task"), the level of need drops considerably to 48.9 percent. Unmet need (no or insufficient help when help is needed) in at least one activity is reported by 21.7 percent of the sample, and formal services (agency or paid help) are used by approximately one-quarter of the sample.

**Future Plans**—Current and future analyses will examine change in need and formal service use over time. Bivariate and multivariate techniques will be utilized to model the determinants of unmet need and the use of formal services. Additionally, caregiver burden will be related to inadequate patient care. Whether or not burden is alleviated by the introduction of formal services will be examined.

#### **Publications Resulting from This Research**

None reported.

### **[525] A Study of Treatment Choices Affecting Elderly Cancer Patients**

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**Sponsor:** *National Cancer Institute, National Institutes of Health*

**Purpose**—The original study of cancer treatment choices identified all newly diagnosed breast, lung, and colorectal cancer patients between 45 and 90 years of age in nine of Rhode Island's 13 general hospitals between late 1984 and early 1986 (constituting 85 percent of all such cases per year). The purpose of the study was to determine whether older

patients who were diagnosed with more advanced disease, delayed seeking care for symptoms and received less aggressive cancer treatment than did younger patients, controlling for the presence of other diseases, disease severity, and patients' performance status.



**Methodology**—Tissue diagnosis of primary lung, breast, and colorectal cancer was confirmed for a total of 1,597 persons. Physicians were contacted to indicate their post-diagnostic treatment recommendations and all surgical, radiation, and chemotherapy treatments administered by Rhode Island providers in the 2 years following diagnosis were documented. A subset of 700 patients were interviewed about physical functioning, the presence of symptoms, health related quality of life, and psychosocial adjustment. The initial interview occurred within 2 months of diagnosis, and follow-up interviews were attempted 3 months later, and at 1 and 2 years post-diagnosis.

**Results**—Study findings revealed that older persons were not more likely to be diagnosed at a more advanced stage of cancer than were younger patients and that older patients who noticed suspicious symptoms were not more likely to delay seeking medical attention than were younger patients. We examined differences in patterns of clinical treatment by establishing for each type of cancer a criterion as to what constitutes “definitive” treatment following diagnosis. We found that older breast cancer patients with local disease who had breast-conserving surgery were less likely to have the recommended radiation therapy than were clinically similar younger patients. A similar relationship was found for women with regional breast cancer at diagnosis insofar as receipt of postsurgical chemotherapy is concerned. Additionally, older lung cancer patients were more likely to receive postsurgical treatments such as chemotherapy or radiation than colorectal cancer patients. While our data permit only limited examinations of why such biases exist, in the case of breast cancer, older patients appear to have been less likely to be referred for subsequent

treatment. However, our data also confirmed the fact that once older patients initiate postsurgical treatment, they are not more likely to miss treatments or drop out than are younger patients, and the treatment intensity is comparable to that for younger but otherwise similar patients.

### Publications Resulting from This Research

- Cancer Patients' Quality of Life Over the Disease Course: Lessons from the Real World.** Mor V, *J Chronic Dis* 40(6):535-544, 1987.
- Work Loss, Insurance Coverage, and Financial Burden Among Cancer Patients.** Mor V, in *Proceedings of the Workshop on Employment Insurance and the Patient with Cancer*, The American Cancer Society, 1987.
- The Brown University Cancer and Aging Study: A Statewide Cooperative Investigation.** Mor V, Guadagnoli E, Masterson-Allen S, Silliman RA, Weitberg AB, Glicksman AS, Rosenstein R, Cummings FJ, Goldberg RJ, Fretwell MD, *Rhode Island Med J* 1:379-386, 1988.
- Influence of Non-Medical Factors in the Choice of Lung Cancer Treatment.** Mor V, Guadagnoli E, Silliman RA, Glicksman A, Weitberg AB, Cummings FJ, Goldberg RJ, *New Engl J Med* 319(10):652, 1988.
- Lung, Breast, and Colorectal Cancer: The Relationship Between Extent of Disease and Age at Diagnosis.** Mor V, Guadagnoli E, Masterson-Allen S, Silliman R, Glicksman AS, Cummings FJ, Goldberg RJ, Fretwell MD, *J Am Geriatr Soc* 36:873-876, 1988.
- Management of Colorectal Cancer in Elderly.** Cummings FJ, Mor V, Guadagnoli E, Glicksman AS, Silliman RA, Weitberg A, Goldberg RJ, *J Am Med Assoc* 260:924, 1988.
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- Pre-Diagnostic Symptom Recognition and Help Seeking Among Cancer Patients.** Mor V, Masterson-Allen S, Goldberg R, Guadagnoli E, Wool MS, *J Community Health* (in press).

## [526] Nurse Interventions Promoting Self-Help Response to Cancer

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**Sponsor:** National Cancer Institute, National Institutes of Health

**Purpose**—The purpose of this study is to: 1) determine the efficacy of promoting patient self-care during cancer treatment for women having a diagno-

sis of breast cancer through nurse interventions that provide information, enhance patients' ability to use the information and/or support uncertainty-re-



ducing interpretations of illness-related events; 2) describe person, disease, contextual factors, and time as variables that enhance or limit self-care activities during and following breast cancer treatments; and, 3) describe the efficiency of a model of nursing care for women with breast cancer within a health maintenance organization (HMO), a tertiary treatment center (Cancer Center), and within private practice sites.

**Methodology**—The  $3 \times 2 \times 2$  randomized block, repeated measure design includes three analysis components: 1) a multivariate experimental analysis of nurse intervention, effect, and durability relative to four outcomes (self-care, self-help, life quality, and morbidity); 2) covariance analysis and multiple regression/correlation analysis of effects on the

learned process of self-help during cancer experience that include testing the influence of concomitant variables grouped into person, disease, and contextual categories, and of time; and, 3) a cost-effectiveness analysis of a program of nursing care offered to selected cancer patients with an HMO, a Cancer Center or a private physician care setting.

**Progress**—The study is in its 6-month start-up phase. We are in the process of Focus Group based data collection to input planned intervention protocols, and within a month of pilot work on recruitment protocols, instruments, and interventions.

#### **Publications Resulting from This Research**

None to date.

### **[527] Neuropsychological Assessment of Children with Cancer**

**Donna R. Copeland, PhD; David J. Francis, PhD; Joann L. Ater, MD; Robin Morris, PhD; Nicholas S. Krawiecki, MD; Jan van Eys, MD, PhD; Donald Pinkel, MD; Norman Jaffe, MD; Ian Butler, MD**  
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**Sponsor:** *National Cancer Institute, National Institutes of Health*

**Purpose**—The goals of this project are to identify and monitor the effects of cancer and its treatment on the neuropsychological development of children. A large cohort of children with leukemia and solid tumors were followed for 3 years from the time of diagnosis. The current study extends that investigation to periods of 6 to 8 years post-diagnosis. In addition, it will generate a cross-validation sample of brain tumor and other cancer patients for comparison purposes.

**Methodology**—Approximately 100 patients are being evaluated at 6-, 7-, and 8-year follow-ups. An additional 120 patients with brain tumors and 120 patients with leukemia and solid tumors are being assessed at diagnosis and four follow-ups. Tests administered to all patients measure abilities and skills in IQ, academic achievement, language, memory, motor, visual-motor, somatosensory, attention, and psychosocial functions. Medical, neurological

and treatment data are being gathered prospectively, including information such as duration and type of physical symptoms, neurological abnormalities, pre-existing medical conditions, neuroendocrine status, neuroimaging studies, and chemotherapy, surgery, and radiotherapy parameters. Patterns of decline and growth will be assessed using a hierarchical linear modeling approach. Medical characteristics will be used both as control variables and as explanatory variables in assessing the effects of the disease and treatment on children.

**Results**—Current results suggest that neuropsychological performance of children with leukemia who received central nervous system (CNS) treatment with chemotherapy (no irradiation) does not differ significantly on measures of IQ, academic achievement, language, and memory from that of children with solid tumors, who received no CNS treatment. In other words, CNS treatment with



chemotherapy apparently does not have a deleterious effect on higher order cognitive functions, at least in the first 3 years post-diagnosis.

Treatment effects associated with systemically administered chemotherapy were detected on fine-motor tasks and stereognosis, thus validating clinical observations of peripheral neuropathy. It is too early to know whether these peripheral effects are transient or permanent.

Other medical variables found to have an adverse effect on neuropsychological performance include a history of seizures and anticonvulsant medication, disease relapse, and cranial radiation therapy. Children with these events in their medical histories tend to perform less well in a wide range of skills and abilities.

The results of studies assessing academic achievement and school-related issues indicate that prior to diagnosis, children with cancer have missed a normal amount of school. During the year of diagnosis, however, the average number of days absent is more than 50. Absenteeism continues to be high 3 and 4 years post-diagnosis, when these children still miss approximately 20 days per school year. Social competency factors (Achenbach Child Behavior Checklist Total T score), particularly those related to school behaviors, are highly correlated with academic achievement scores, as is psychological adjustment as measured by the Personality Inventory for Children. Current studies are investigating the relative importance of school absenteeism, medical, and psychosocial factors in the academic performance of children with cancer.

In studies of patients with brain tumors, we found that the mean scores of 31 patients who were assessed prior to medical treatment (surgery, radiotherapy, chemotherapy) were within normal limits in intelligence, academic achievement, language, memory, visual-motor and constructional skills, fine-motor skills, and executive functions. When this group was divided by location of the tumor in the brain (cerebral, midline, posterior), the results were unchanged, except that the cerebral tumor group was impaired in executive functions. When the groups were divided by presence/absence of hydrocephalus, the hydrocephalus group scored lower on most measures, although their scores were within normal limits and differences were not statistically significant. The results of this study

suggest that many of the observed deficits among brain tumor patients that are reported in the literature are most likely to be a function of treatment rather than the tumor itself.

In another investigation of the relative effects of cranial radiation therapy (CRT) and age at diagnosis (DA) on the neuropsychological performance of 78 brain-tumor patients, multiple regression statistical analyses indicated that CRT was predictive of lower verbal memory and fine-motor scores, regardless of DA. By comparison, younger DA was predictive of lower performance IQ and visual-spatial scores, regardless of CRT status. Further analyses indicated group differences along other dimensions as well. These results suggest that CRT and DA are important and dissociable predictors of neuropsychological functions.

These findings are important in their relevance to the medical treatment of children with cancer and their potential to achieve scholastic and occupational goals. Studies are continuing, with efforts focused on developing neuropsychological growth curves for children with cancer and identifying factors that will be predictive of deficits in performance.

### Publications Resulting from This Research

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- Arithmetic Error and Neuropsychological Test Profiles Among Arithmetic Disabled Groups.** (Abstract), Dowell R, Fletcher J, Francis D, Copeland D, *J Clin Exp Neuropsychol* 10(1):56, 1988.
- The Association Between Hearing Loss Secondary to Cis-Diamminedichloroplatinum-II (CDP) Treatment, IQ, and Academic Achievement (ACH).** (Abstract No. 1036) Copeland DR, Judd BW, Ruiz L, Jonsdottir M, Jaffe N, in *Proceedings, American Society of Clinical Oncology*, 267, 1988.
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- Neuropsychological Effects of Childhood Cancer Treatment.** Copeland DR, Dowell RE, Fletcher JM, Sullivan MP, Jaffe N, Frankel LS, Ried HL, Cangir A, Bordeaux JD, *J Child Neurol* 3:53-62, 1988.
- Neuropsychological Performance in an Untreated Brain Tumor Population: Implications for a Taxonomy.** (Abstract), Judd BW, Dowell RE Jr, Copeland DR, *J Clin Exp Neuropsychol* 10(1):45, 1988.



**Neuropsychological Test Performance of Pediatric Cancer Patients at Diagnosis and One Year Later.** Copeland DR, Dowell RE Jr, Fletcher JM, Sullivan MP, Jaffe N, Cangir A, Frankel LS, Judd BW, *J Pediatr Psychol* 13(2):183-196, 1988.

**A Prospective Study of Neuropsychologic Sequelae in Children with Brain Tumors.** Bordeaux JD, Dowell RE, Copeland DR, Fletcher JM, Francis D, van Eys J, *J Child Neurol* 3:63-68, 1988.

**Synergistic Effects of CNS Treatments Among Children.** (Abstract), Dowell R, Francis L, Copeland D, Fletcher J, *J Clin Exp Neuropsychol* 10(1):46, 1988.

**Academic and Neuropsychological Progress of Arithmetic Underachieving and Normally Achieving Children with Cancer.** (Abstract No. 1228) Myers deR, Copeland D, Moore B, Jaffe

N, in *Proceedings, American Society of Clinical Oncology*, 8:315, 1989.

**Effects of Cranial Radiation Therapy (CRT) and Age at Diagnosis (DA) on Neuropsychological Performance in Pediatric Brain Tumor Patients.** (Abstract), Schmidt M, Copeland DR, Fletcher J, *J Clin Exp Neuropsychol* 11(1):30, 1989.

**Neuropsychological Effects of Chemotherapeutic Agents.** Dowell RE Jr, Copeland DR, Judd BW, *J Dev Neuropsychol* 5(1):17-24, 1989.

**Neuropsychological Performance of Pediatric Cancer Patients in Remission and in Relapse.** (Abstract), Moore BD, Copeland DR, *J Clin Exp Neuropsychol* 11(3):364, 1989.

## [528] Self-Care Intervention to Decrease Chemotherapy Morbidity

**Marylin J. Dodd, RN, PhD, FAAN; Patricia Larson, RN, DNSc; Kathleen Stetz, RN, PhD; Brian J. Lewis, MD; Bill Holzemer, RN, PhD, FAAN; Walter Hauck, PhD; Ada Lindsey, RN, PhD, FAAN; Emilie Musci, RN, DNSc**  
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**Sponsor:** National Cancer Institute, National Institutes of Health

**Purpose**—The purpose of this proposed study is five-fold: 1) to test the effectiveness of nursing intervention (PRO-SELF) in enhancing self-care in persons with cancer; 2) to determine if self-care reduces patients' morbidity associated with selected potent chemotherapy agents; 3) to test the effectiveness of PRO-SELF in reducing morbidity; 4) to determine patient, system, tumor, and treatment characteristics which predict, facilitate, and limit the utilization of self-care during a 4-month period of chemotherapy; and, 5) to determine the characteristics of patients who do not participate in self-care. Theories of coping and self-care provide the conceptual framework for the study.

The nursing intervention program PRO-SELF is a self-care program for the chemotherapy patient. It is a nurse-initiated informational-interactive chemotherapy-cycle-specific program designed to enhance patients' self-care abilities in reducing the morbidity associated with the side effects of chemotherapy.

**Methodology**—An experimental longitudinal design (4 months) will be used with random assignment to the experimental or control group. Morbidity, the major dependent variable for the study will include:

number and extent of chemotherapy-related complications; tolerance of patients to chemotherapy; health care services received by the patients; selected physiological parameters and physical functioning. Potential intervening variables include characteristics of the patient's health care system, tumor, and treatment. The sample will include 120 patients who are receiving either carboplatin, cis platinum, doxorubicin, methotrexate, cyclophosphamide, or fluorouracil and their primary family caregivers (n=120). Repeated measures of the dependent and intervening variables will occur at selected times during four data collection points. Semi-structured interviews, medical record chart review, self-administered questionnaires, and self-report logs are the methods for obtaining data. Findings will lead to cancer nursing care models and interventions that will promote self-care and diminish morbidity during cancer treatment.

**Progress**—To date, 24 subjects have consented to participate in this trial of a nursing intervention to decrease chemotherapy-induced morbidity. Seventeen nurses have been trained to perform the intervention, and 22 staff nurses have been trained



to complete the in-home interviews. Results have not been computed yet, but we anticipate some preliminary results in the next year.

**Publications Resulting from This Research**

None reported.

**[529] Living with Homecare: Cancer Patients and Their Caregivers**

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**Sponsor:** *National Cancer Institute, National Institutes of Health*

**Purpose**—Recent efforts at cost containment have contributed to a shift from hospitalizing cancer patients who are receiving radiation therapy to offering these services on an outpatient basis to cancer patients who are living at home. With the shift to homecare comes a number of problems. Little documentation exists on the health care service utilization patterns of cancer patients living at home, the extent to which existing services and insurance coverage meets their needs, their levels of satisfaction with services, their health care expenses, and the impact of outpatient care on patients and their families.

**Methodology**—Adult cancer patients who are beginning radiation therapy will be recruited into the study. Criteria for entry into the protocol includes being age 45 years or older, the high likelihood of ongoing care needs related to cancer and cancer treatment, life expectancy of at least one year, and non-institutional residence.

Patients (and their primary caregivers) will be interviewed during radiation therapy and twice thereafter at four-month intervals. Major variables will include demographic data, physical health and

functional status, psycho-social variables such as measures of depression, stress, optimism, and social support, the need for homecare and other services, and the costs of medical care incurred by the patients and caregivers. Caregivers will be asked about the amounts of stress and burden they experience, as well as their needs for medical and homecare services for the patient.

Medical records will be examined to collect information on diagnosis, type and site of cancer, prior therapy and outcomes, medications prescribed, and changes in health care status while the patient participates in the protocol. Home health charts will be examined to extract information on the utilization and efficacy of these services. Agencies providing services to the patients will be contacted to collect information on costs and service utilization.

**Progress**—The study is currently in its initial stages of recruitment, and is scheduled to continue through January of 1992.

**Publications Resulting from This Research**

None reported.

## XVII. Miscellaneous

*For additional information on topics related to this category see the following Progress Reports: [22], [23].*

### [530] Evaluation of One-Way Air Flow Valve Prostheses in Decannulation Procedures for Chronic Tracheotomized Patients

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**Sponsor:** *VA Rehabilitation Research and Development Service Development (Project #C468-RA)*

**Purpose**—This research proposal has two objectives. First, we wish to determine which diagnostic tests can be performed that will be useful in identifying those patients who can be weaned from their chronic tracheotomy. Second, we wish to determine if a new technique, using the Passy-Muir one-way valve, results in a higher success rate and/or shorter period of weaning.

**Progress**—In the 23 months since the project was initiated, 40 patients with chronic tracheostomies have been evaluated. Twenty-eight of these patients were excluded from further study because they did not meet our inclusion criteria. Reasons for exclusion included unstable medical condition (12), upper-airway obstruction (8), sleep apnea syndrome (2), and in process of being decannulated (6).

**Results**—Twelve patients entered the main part of the study. Initially 6 patients were randomized to the standard capping method and 6 to the Passy-Muir one-way valve. Weaning was successful in all but two of the patients who were randomized. One of the patients who failed was tried with both procedures. The other failure occurred in a patient who died of cardiovascular disease shortly after being randomized. The FEV<sub>1</sub> and the maximal inspiratory pressures did not distinguish the failure to wean patients from the successes. The mean time for

weaning was 18 days (range 14-24) with the one-way valve, 23 days (range 8-36) for the standard capping.

**Implications**—We found that weaning is a difficult, time-consuming procedure in these patients. Patients who can tolerate capping of their tracheostomy for 45 minutes are good candidates for decannulation. Standard measures of pulmonary function do not appear to be helpful in predicting which patients are likely to be successfully weaned. Although the time to decannulation was not significantly shorter with the one-way valve, patient comfort appeared better with the one-way valve.

Based on our experiences, we make the following recommendations for patients who are undergoing decannulation: 1) patients should be monitored constantly with ear oximetry with alarms set during all attempts at weaning; 2) the level of upper-airway resistance can be assessed by measuring the pressures at the tracheostomy opening to assess upper-airway resistance; and, 3) prior to decannulation, an endoscopic examination of the upper airways should be performed to determine whether there is gross aspiration and if laryngeal protective functions are present.

#### **Publications Resulting from This Research**

None reported.



### [531] Dissemination of Rehabilitation Technologies

**Alvin H. Sacks, PhD; Richard D. Steele, PhD; Robert A. Weisgerber, EdD; Terry R. Armstrong, PhD**  
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 American Institutes for Research, Palo Alto, CA 94302

**Sponsor:** VA Rehabilitation Research and Development Service (Project #F259-OA)

**Purpose**—Our primary goal was to produce guidelines for effective technology transfer of products, processes, and findings designed for investigators involved in rehabilitation research and development. Our secondary goal was to inform policymakers in the VA about aspects of the transfer process that can be facilitated through policy changes.

**Progress**—During the first year of this 3-year project, we gathered information from selected members of the rehabilitation community, technology development centers, and manufacturers. We created a framework for describing the process of transferring rehabilitation technology from the design stage to manufacturing. Next, we surveyed all the projects at the Palo Alto Rehabilitation Research and Development (Rehab R&D) Center and conducted interviews with selected engineers whose projects were in different stages of development.

With this background, we drafted a *Guide*

which is tailored to the roles of Investigators, the Transfer Officer, and the Center Director. It informs readers about the process of technology transfer at the national, center, and project levels; provides general guidelines for designing and conducting projects to enhance transferability of the technology being developed; and suggests specific steps involved in key decision points, such as entering into agreements with manufacturers, making disclosure statements, applying for patents, and arranging licensing.

**Results**—The *Technology Transfer Guidebook* has been printed and distributed.

#### **Publications Resulting from This Research**

**Technology Transfer Guidebook.** Weisgerber RA, Armstrong TR, Sacks AH, Steele RD, Palo Alto: Rehab R&D Center, 1989.

### [532] Rehabilitation Effects of Expectation, Reward, and Activity on Subtypes of Schizophrenia

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 VA Medical Center, West Haven, CT 06516

**Sponsor:** VA Rehabilitation Research and Development Service (Project #D515-RA)

**Purpose**—The purpose of this research is to investigate the benefits of productive activity in the rehabilitation of patients with a diagnosis of schizophrenia. The key questions are: 1) Does greater expectation for productive activity lead to more productivity? 2) Does greater productivity lead to better rehabilitation outcomes? 3) Does pay act as a reward for schizophrenic patients in a work program leading to greater productivity, greater job satisfaction, and increased self-esteem? 4) Does greater expectation increase the likelihood of relapse and rehospitalization? and, 5) Are subtypes of schizophrenia based on psychological and neurobehavioral

measures useful predictors of rehabilitation outcome?

**Methodology**—In an experimental control group design, 150 patients recruited from the general psychiatric service, including the mental hygiene clinic, with a diagnosis of schizophrenia confirmed by SADS-RDC, will be assigned through stratified randomization (by premorbid history and negative symptoms) to three levels of expectation for work. N: *No Expectation* = 30, *Low Expectation* (10 hours per week required) = 60, *High Expectation* (20 hours per week required) = 60.

Subjects in the *Low Expectation* and *High Expectation* conditions will be offered work through the Incentive Work Therapy Program (IWT); those in the *No Expectation* group will not. The IWT provides up to 20 hours of work per week in a variety of placements throughout the Medical Center, with duties similar to those of regular hospital employees. All subjects will attend weekly group sessions where, across all conditions of expectation, support is provided, conditions of expectations are reinforced, and weekly information on productivity and measures of clinical status are obtained. Research staff will also evaluate productivity through on-site, time-sampled monitoring of attendance and productivity, and through supervisors' weekly evaluations.

For 3 months of the active intervention, subjects will receive weekly pay at a rate of \$3.40 per hour of productive activity; and for 3 months, subjects will be asked to work without remuneration. To examine order effects, subjects will be randomly assigned to receive pay either in the first or the second 3 months of their involvement. Subjects in the *No Expectation* control group will

also receive payment for verified productive activity during the pay condition of the active intervention. Subjects will be evaluated on demographic, neurobehavioral (negative symptoms, smooth pursuit eye-tracking, Wisconsin Card Sort) and productivity measures at baseline. They will be interviewed at the conclusion of the 6-month intervention and at 12-month follow-up from program entry to assess their clinical status, productivity, and other measures of rehabilitation outcome.

Data analysis employing descriptive and inferential statistical methods will examine main effects, interaction effects, and the predictive value of sub-type schemes to answer the key questions of the study.

**Implications**—Results of this study should provide guidelines for expectation, reward, and amount of activity in planning programs of productive activity appropriate to the rehabilitation of schizophrenic veterans.

#### **Publications Resulting from This Research**

None reported.

### **[533] Major Study on Alcohol, Drugs, and Disability**

**John de Miranda, EdM**

California Alcohol, Drug, and Disability Study, San Mateo, CA 94402

**Sponsor:** *California Department of Alcohol and Drug Programs*

**Purpose**—The California Alcohol, Drug and Disability Study (CALADDS), believed to be the first of its kind in the U.S., has been completed. It assessed the treatment and prevention need of individuals with disabilities among California's 27 million residents. The CALADDS Project identified obstacles to prevention and recovery services and made recommendations to the state to improve access to California's alcohol and drug service system.

**Results**—The study encourages the state of California to declare persons with disabilities to be at high risk for alcohol and other drug-related problems,

and urges the adoption of 30 remedial policy recommendations.

Study findings include: 1) 63.7 percent of disability service agencies responding indicated a need for training or technical assistance in identification and assessment of alcohol and drug problems; 2) 65.5 percent of disability service agency staff believe that community-based residential alcohol/drug treatment programs are either *not accessible* or only *somewhat accessible*; 3) 53.9 percent of individuals with disabilities interviewed who sought help for an alcohol or drug problem experience a negative accessibility problem; and, 4) 16.7 percent of individuals with disabilities inter-



viewed indicated that alcohol or drug use was a contributing factor in the acquisition of their disability.

### **[534] State-Wide Interagency Planning Council on Technology Access for Persons with Disabilities**

**William C. Mann, OTR, PhD**

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*Sponsor: Office of Special Education Programs, Department of Education*

**Purpose**—The New York State (NYS) Interagency Planning Council on Technology and Disabilities was formed to: 1) establish a process of planning technology utilization in New York; 2) enhance communication and cooperation among state, local, and private agencies; and, 3) continue the work of a previous planning body, the NYS Governor's Task Force on Technology and Disabilities, through accomplishment of tasks related to the recommendations in their final report.

**Methodology**—The Planning Council was formed in October, 1988, following notification of award on a federal grant to support the activities of the Council. Commissioners of state agencies were asked to appoint representatives to the Planning Council. Private agencies, technology companies, and consumers were also asked to sit on the Planning Council. The Planning Council meets three times a year in Albany, the state capital.

**Progress**—The initial Planning Council meetings focused on information dissemination and funding issues. A large group, the structure of the meetings was changed from open sessions to a format that included presenting reports on a topic, breaking down into small groups for discussion and ideas on problem resolution, and reporting back to the full council. A caution for other states in establishing such councils is to be certain that representatives with much computer experience understand the

### **Publications Resulting from This Research**

**Executive Summary of the California Alcohol, Drug and Disability Study.** San Mateo, CA: The Coalition on Disability and Chemical Dependency, 1989.

difference between the world they work in—which may be state-of-the-art—and the world of consumers and direct service providers, which is rarely state-of-the-art.

**Preliminary Results**—The Planning Council established, as its first two priorities, issues related to information dissemination and funding. Overall planning is proceeding, and substantive outcomes have been achieved.

Recommendations for other states considering establishment of such a planning group are: 1) appointment of committed, knowledgeable, realistic people to the planning group; 2) the size of the planning group will impact on its manner of functioning. Highly structured meetings are recommended, and once policy is decided, the details of implementation should be determined by smaller working groups; 3) politics and "turf" issues are real, and must be recognized; and, 4) issues of accommodation must be considered and addressed.

**Future Plans**—The Planning Council will continue for one year under the direction of the project director, and then responsibility will be transferred to the NYS Office of the Advocate for the Disabled.

### **Publications Resulting from This Research**

**Model for Interagency Coordination of Technology Resources.** Mann WC, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 341-342, 1989.

### [535] Establishing a State-Wide Technology Information Network

**William C. Mann, OTR, PhD; Joseph Lane, MBA, MPH**

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**Sponsor:** *Office of Special Education Programs, Department of Education*

**Purpose**—The New York State Technology Information Network (TIN) was initiated as a component of the project, *Model for Interagency Coordination of Technology Resources*. There are many agencies in New York providing services relating to assistive technology, but no one can say who is doing it, where it is occurring, and what exactly is being done. The problem confronting persons with disabilities is the lack of access to available information on special devices and adaptation to existing devices that could increase functional independence pertinent to their lives. The purpose of TIN is to coordinate access to information and services on assistive technology in New York. On a second level, TIN can serve as a model for similar networks in other states.

**Methodology**—The New York State Interagency Planning Council on Technology and Disability considered development of TIN a major priority. The overall structure was approved by the Planning Council. More detailed planning was carried out by a special TIN task force. A survey form was mailed to approximately 3,000 service providers in New York, excluding school systems. The survey requested information on center or consultant name, address, and phone number; and for organizations, a contact person. Additional questions, to be used later as sort variables, were asked on geographic region served, disability category and age groups to which services are provided, and a number of questions on the types of technology-related services offered. Respondents were asked to provide a short

narrative description of the type of services and types of technology applications available at the center.

**Progress**—Over 100 surveys were returned and entered into a DBase IV database. A first edition of the *Technology Information Network Directory* has been printed and distributed. This first edition is primarily to provide an opportunity for respondents to check the accuracy of the data. The New York State Education Department is presently mailing an additional 760 surveys to all school systems in New York, which will be added to the database.

**Preliminary Results**—Reaction to the survey has been positive, but the real test of the system will come with consumer and service provider evaluation over the next year.

**Future Plans**—Codes for a front-end system for computer linkage were written, and the system has been in place since October 1989, with an 800 number. The database was also linked to an existing service information system operated by the New York State Office of the Advocate for the Disabled in Albany, and has been in place since September 1989 (also with an 800 number). The database will be continually updated and the TIN directory printed quarterly.

#### **Publications Resulting from This Research**

**New York State Technology Resources Information Network**, Mann WC, Lane J, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 339-340, 1989.



### [536] Consumer Role in State-Wide Planning for Access to Assistive Technology

**William C. Mann, OTR, PhD**

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**Sponsor:** *Office of Special Education Programs, Department of Education*

**Purpose**—Inclusion of consumers is a key component of the project, *Model for Interagency Coordination of Technology Resources*. On a state-wide level, this project is attempting to address problems related to access of assistive technology by persons with disabilities and by persons involved with direct service provision. The goal is to establish a model for including consumers and service providers in the identification of problems, and in suggesting plans of action for problem solutions.

**Methodology**—A series of one day "Grass Roots Meetings and Workshops," are being held across New York State. Some of these meetings were held in 1989, and several more are planned for the next project year. Participants introduce the project, discuss work in progress, and work completed. They also develop written statements about their experiences with technology, their views of the problems, and their suggestions for solutions. Participants and project faculty discuss technology access problems.

**Progress**—This model appears practical and useful for state-wide planning. Helping to shape priorities for action, the consumer-service provider statements are channeled to the New York State Interagency Planning Council.

**Preliminary Results**—Major consumer-service provider concerns, in order of priority are: 1) finding ways to fund assistive technology; 2) keeping up-to-date—having information and, where appropriate, training on the latest technology; 3) being included—both in state-wide processes addressed by this project, and individually in evaluation, prescription, and modification; consumers reject the medical model with need for a physician team leader, feeling they know what they need and can direct efforts at provision of their assistive technology; and, 4) recognition of individual differences; avoidance of highly prescriptive systems such as a listing of jobs that persons with certain types of disabilities could do.

**Future Plans**—The Grass Roots Meetings and Workshops have been continued into 1990. A final analysis will focus both on content and process. The New York State Office of the Advocate for the Disabled will assume primary responsibility for continuing the process of consumer involvement after the second project year.

#### **Publications Resulting from This Research**

None reported.

### [537] Computerization of Patient Care Activities

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VA Medical Center, Bronx, NY 10468

**Sponsor:** *Eastern Paralyzed Veterans Association*

**Purpose**—Documentation of medical care suffers from fragmentation, lack of standardization, and varying degrees of comprehensiveness. Thus, the ability and effectiveness to retrieve and analyze pertinent data is limited and costly. This project will use microcomputers to develop a method of documentation that is both acceptable and usable.

Considerations in this regard include: low set-up expense allocations, flexibility to meet the needs of a wide variety of clinical programs/settings, and a user-friendly system that will be accepted by health professionals with limited computer literacy/skills.

The current project involves the development of a format for documentation, retrieval, and analysis

of patient-care data, designed to meet the needs of most long-term care programs, with subsequent development of many of the ambulatory care programs.

The major patient care documentation program consists of three core modules (demographics, historical data, physical examination data) that can interface with specialized satellite modules, designed to be program-specific. Another part of this project (the infection control program) is designed to assist health care professionals in their clinical activities. The final project has the potential for improved quality and cost-effectiveness of patient care.

**Progress**—Development of the “infection control” program, based on D Base III, was completed. It

was tested, debugged, and works as expected. Work on the medical history and physical examination database programs (based on DATAEase) is continuing. The physical examination module is almost complete, the medical history and demographic modules 80 percent complete, and the development of some satellite modules has started.

**Future Plans**—Future plans include continued implementation of the infection control program and the development of the physical examination module of the medical records project.

#### **Publications Resulting from This Research**

None reported.

### **[538] Developing Consumer Criteria for Evaluating Assistive Devices**

**Andrew I. Batavia, JD, MS; Guy Hammer, BSEE, PE**

National Rehabilitation Hospital Research Center, Washington, DC 20010; University Research and Biomedical Applications Program, Strategic Defense Initiative Organization, Washington, DC 20301-7100

**Sponsor:** *National Institutes on Disability and Rehabilitation Research*

**Purpose**—The purpose of this preliminary study was to develop a set of prioritized consumer-based criteria for the evaluation of assistive devices.

**Progress**—The first year of this study has been completed. A modified version of the Delphi method was applied to two groups of long-term users of assistive devices in evaluating 11 types of assistive technology. Consumer criteria for evaluating assistive devices were identified and prioritized.

**Results**—The study identified and prioritized 17 consumer criteria for the assessment of assistive devices. In order of the priorities assigned by the consumer panels, they are:

1. **Effectiveness:** the extent to which the functioning of the device improves the consumer's living situation, as perceived by the consumer, including whether it enhances functional capability and/or independence.

2. **Affordability:** the extent to which the purchase, maintenance, and/or repair of the device causes financial difficulty or hardship to the consumer.

3. **Operability:** the extent to which the device is easy to operate and responds adequately to the consumer's operative commands, including whether controls and displays are accessible and whether start-up time for each use is excessive.

4. **Dependability:** the extent to which the device operates with repeatable/predictable levels of accuracy under all conditions of reasonable use.

5. **Portability:** the extent to which the device can readily be operated in different locations, including whether the length of battery charge and the size and weight of the device permit physical relocation.

6. **Durability:** the extent to which the device will continue to be operable for an extended period of time.

7. **Compatibility:** the extent to which the device will interface with other devices currently and in the future.

8. **Flexibility:** the extent to which the device is provided with available options from which the consumer may choose.

9. **Ease of Maintenance:** the extent to which the consumer (or his or her personal assistant) can easily



maintain the device to keep it operable and safe, including whether it is easy to conduct all required maintenance, cleaning, and infection control procedures.

10. **Securability:** the extent to which the device can easily be kept within the physical control of the consumer to reduce the likelihood of theft or vandalism.

11. **Learnability:** the extent to which the consumer, upon initially receiving the device, can easily learn to use it and can start using it within a reasonable period of time once assembled, including whether specialized training is required.

12. **Personal Acceptability:** the extent to which the consumer is psychologically comfortable in using the device in public (or even in private), including whether the device is aesthetically attractive.

13. **Physical Comfort:** the extent to which the device causes physical pain or discomfort to the consumer.

14. **Supplier Repairability:** the extent to which a local supplier or repair shop can repair the device within a reasonable period of time, including whether replacement parts are readily available and whether the manufacturer must conduct repairs.

15. **Physical Security:** the extent to which the device is likely to cause physical harm, including bodily injury or infection, to the consumer.

16. **Consumer Repairability:** the extent to which

the average consumer (or his or her personal assistant) can repair the device if broken, including whether special repair equipment is needed.

17. **Ease of Assembly:** the extent to which the consumer (or his or her personal assistant) can easily assemble the device upon receiving it, including whether it is packaged conveniently.

**Future Plans/Implications**—This study constitutes a first step toward the development of a normative theory for evaluating assistive devices. Consumer-based evaluation criteria will help to guide the design, manufacture, and selection of assistive devices. Additional work, which will be conducted jointly by the Connecticut Rehabilitation Engineering Center (REC) on Service Delivery and the National Rehabilitation Hospital REC on Technology Evaluation, will include the following: 1) assessing the validity and reliability of the developed criteria using a larger sample of long-term users of assistive devices; 2) determining the relative weight of each of the developed criteria; and, 3) developing a protocol for training recently disabled persons to use the criteria in making purchasing decisions, and testing the value of the criteria in making such decisions.

#### **Publications Resulting from This Research**

None reported.

### **[539] Primary Care for Persons with Physical Disabilities in the Netherlands**

**Andrew I. Batavia, JD, MS**

National Rehabilitation Hospital Research Center, Washington, DC 20010

**Sponsor:** *National Institute on Disability and Rehabilitation Research*

**Purpose**—This international research fellowship examined current approaches in the Netherlands to meeting the post-rehabilitation primary health care needs of persons with severe physical disabilities. The Netherlands was selected for this fellowship because of: 1) its strong commitment to addressing the comprehensive health care needs of its population generally; 2) its particular commitment to meeting the needs of persons with disabilities; 3) its interesting primary care system in which each Dutch citizen is entitled to primary care provided by a

general practitioner (called a “huisartz”) located in his or her community; and, 4) certain similarities between the Dutch and U.S. health care financing systems that suggest the lessons learned in the Netherlands may be applicable, at least in part, to the U.S.

**Progress**—Prior to visiting the Netherlands, the researcher conducted extensive library research on the Dutch health care and social insurance systems. Upon arriving in the country, the researcher met



with his three Dutch primary fellowship contacts who scheduled meetings and coordinated other activities for the fellowship. Subsequently, the researcher met with and interviewed health care administrators, physicians, nurses, social workers, allied health professionals, policymakers, and persons with disabilities to determine the strengths and weaknesses of approaches that have been taken to address the health care needs of disabled persons. Over 30 structured interviews were conducted over the course of the study.

Among the issues addressed were how the system determines which services are covered for persons with disabilities, and what happens when there is a dispute; whether the system adequately addresses the needs of persons with disabilities, and what needs are not adequately met; whether the system has safeguards against over-utilization and/or under-utilization of health care services; how

the system addresses issues of access to durable medical equipment, including the repair of such equipment; and how the system addresses health-related issues such as access to dependable attendant care and emergency attendant care.

**Results/Implications**—The results of this fellowship currently are being prepared for publication. Until recently, there has been very little research and practically no policy consideration of the primary health care needs of persons with disabilities in the U.S. Documentation through this research fellowship of approaches used in the Netherlands will help to focus the attention of researchers and policymakers in this country on this important area, and may result in innovative demonstration projects.

#### **Publications Resulting from This Research**

None reported.

### **[540] Comparison of the Costs of Supporting Children with Severe Disabilities in Family and Institutional Settings**

**Steven J. Taylor, PhD; James Knoll, PhD; Hank Bersani, Jr., PhD**

Research and Training Center on Community Integration, Center on Human Policy, Syracuse, NY 13244-2340

*Sponsor: National Institute on Disability and Rehabilitation Research*

**Purpose**—The purpose of the research was to examine whether specialized foster family care for children with severe and multiple disabilities is practical and fiscally responsible.

**Methodology**—Previous studies have compared costs of institutional and community services by looking at two sets of (hopefully) comparable individuals. Flaws in that methodology were avoided in the present study by collecting longitudinal data on specific individuals as they moved from institutional settings (mental retardation institutions and nursing homes) into regular family homes (specialized foster care). Total public costs were recorded and analyzed for each child in three situations: 1) the final year of institutional service; 2) the first year of family care; and, 3) the most recent (FY 1986-87) cost information. Primary comparisons were made by individuals across the three data points. Population averages are offered only as a secondary analysis for comparison purposes.

**Results**—Costs for services to this population have increased over time in both institutional and family settings. However, the rate of increase has been much greater in the institutional settings.

Each of the children in the study is currently being served at a cost well below that of the local institution, in spite of the fact that they were all institutionalized themselves for at least one year. Some of the children in the study are being served at one-fourth to one-fifth of the cost of the institutions where they were or would be served.

**Future Plans**—A current report on this project is being developed.

#### **Publications Resulting from This Research**

None to date.



## [541] Qualitative Evaluations of Exemplary Programs

Steven J. Taylor, PhD; Robert Bogdan, PhD; Douglas Biklen, PhD; Dianne Ferguson, PhD; Hank Bersani, Jr., PhD; Julie Ann Racino; Bonnie Shoultz; Pam Walker; Rannveig Traustadottir; Zana Lutfiyya; Rebecca Salon; Dimity Peter; Susan O'Connor

Research and Training Center on Community Integration, Center on Human Policy, Syracuse, NY 13244-2340

*Sponsor: National Institute on Disability and Rehabilitation Research*

**Purpose**—The purpose of the series is the description and evaluation of the innovative and promising practices among programs serving people with developmental disabilities and identified as having exemplary approaches.

**Methodology**—Using qualitative research methods, each investigator visits a program, writes extensive field notes on the visit, and prepares a case study of the program.

**Results**—A series of 18 case studies is now available for purchase through the Research and Training

Center on Community Integration, and an additional four are available as articles or as part of a larger information packet. Reports on five other visits are in draft form.

**Future Plans**—By the fall of 1990, case studies of visits to a total of 40 programs in the United States will have been completed.

### **Publications Resulting from This Research**

None reported.

## [542] Personal Integration Inventory

Steven J. Taylor, PhD; Hank Bersani Jr., PhD; Rebecca Salon, MS

Research and Training Center on Community Integration, Center on Human Policy, Syracuse, NY 13244-2340

*Sponsor: National Institute on Disability and Rehabilitation Research*

**Purpose**—The Personal Integration Inventory (PII) is a survey instrument designed to be used to collect data on the integration levels of individuals with disabilities. The focus of the PII is on the day-to-day activities of a single individual. The instrument has three interrelated purposes: 1) as a research tool, the PII can be used to assess the degree to which an individual is integrated into the community; 2) as an instrument for internal program review, the PII offers program staff an opportunity to record changes in the level of integration of individuals whom they serve; and, 3) as a teaching tool, the PII directs the reader's attention to a wide variety of areas related to the issue of integration.

**Methodology**—Several successive versions of the PII were pilot-tested on individuals being served in

mental retardation programs in the greater Syracuse area. For comparison purposes, the PII was also administered to numbers of non-handicapped people (mostly students in special education courses at Syracuse University). A panel of nationally recognized experts on integration was asked to comment on successive drafts of the instrument as a social validation.

**Results**—The PII is completed.

### **Publications Resulting from This Research**

**Personal Integration Inventory.** Bersani H Jr, Salon R, Syracuse, NY: The Center on Human Policy, 1988.

### **[543] A Managed Primary Health Care Program for Working-Age Persons with Physical Disabilities: Planning for Implementation**

Naomi Naierman, MPA; Ruth W. Brannon, MSPH; Andrew I. Batavia, JD, MS; Gerben DeJong, PhD  
National Rehabilitation Hospital Research Center, Washington, DC 20010

*Sponsor: The Robert Wood Johnson Foundation*

**Purpose**—The purpose of this project is to develop a framework for implementing a managed primary health care program for working-age persons with physical disabilities in the Washington, DC, area. The thesis of the project is that a managed primary care program will enhance access for disabled persons to needed health care services, and will result in decreased utilization by disabled persons of expensive and inappropriate health care services (such as avoidable hospitalizations and emergency room visits).

**Progress**—In phase one of this project, a feasibility study was conducted to determine how disabled persons in the Washington, DC, area currently are receiving primary health care services, and whether there is support in the disabled community for the development of a managed care program. Based upon the results of the study, the research team chose to conduct a demonstration project to test the thesis and to examine issues of program implementation. In the demonstration, a primary health care network will be developed and made available to a small group of persons with physical disabilities (approximately 300). The network will comprise primary care givers and case managers.

To this end, work has progressed in several areas. First, a number of psychiatrists and other specialists in the Washington, DC, area were interviewed to provide the project staff expert advice on developing a primary care program for persons with physical disabilities. Second, disability organizations were contacted to review the feasibility study findings, and to assist with plans for recruiting patients for the demonstration project. Third, the project

staff identified and contacted a number of primary care providers located in the Washington, DC, area to determine whether they would be willing to provide services under the program. Fourth, an advisory panel was convened to assist with methodological and operational issues, such as the definition and role of case management under the program.

**Results**—As a result of this phase of the project, the project staff has compiled an initial list of physicians who are willing to serve in the primary care network. As part of a pre-enrollment process, several disability organizations have provided information to their memberships on the proposed network. Finally, an implementation plan has been prepared, which defines the responsibilities of providers, patients, and case managers under the program.

**Future Plans**—The project staff will implement the primary care network demonstration in the 1990 calendar year. It is anticipated that the demonstration will run for at least 3 years, during which time data will be collected on the health care utilization and costs of disabled persons in the network. From this research, the staff hopes to devise a managed care program that will serve as a model for providing health care services to working-age persons with physical disabilities.

#### **Publications Resulting from This Research**

**A Managed Care Program for Working-Age Persons with Physical Disabilities: A Feasibility Study.** Batavia AI, DeJong G, Burns T, Smith Q, Melus S, Butler D, Washington, DC: National Rehabilitation Hospital Office of Research, 1989.



## [544] Health Insurance-Related Work Disincentives for SSDI Beneficiaries

Gerben DeJong, PhD; Andrew I. Batavia, JR, MS; Thomas J. Burns, MA; Gary Markert, MS, MPH; Marsha G. Meehan

National Rehabilitation Hospital Research Center, Washington, DC 20010

**Sponsor:** Social Security Administration (SSA), U.S. Department of Health and Human Services

**Purpose**—The purpose of this study is to examine disincentives to work associated with concerns of Social Security disability income (SSDI) beneficiaries who would lose their Medicare benefits and might not be able to obtain comparable employment-based health insurance benefits if they obtained gainful employment.

The four objectives of the study are to: 1) develop a theoretical framework for deriving a greater understanding of the relationship between health insurance coverage and employment for SSDI beneficiaries; 2) examine the relationship between health insurance coverage of SSDI beneficiaries and their decisions and capacities to seek, obtain, and maintain employment; 3) examine the private health insurance coverage available to SSDI beneficiaries, including gaps in coverage resulting from insurance exclusions, “pre-existing condition clauses,” and policy “riders;” and, 4) develop policy options on how to reduce insurance-related work disincentives for SSDI beneficiaries, and to enhance their employment potential.

**Progress**—The first year of this two-year study has been completed. Four existing data sets that include SSDI beneficiaries and non-beneficiaries have been prepared for analysis. The four data sets are: 1) the New Beneficiary Survey, conducted on behalf of the Social Security Administration; 2) the Survey of Income and Program Participation, conducted by the U.S. Census Bureau in stages since 1983; 3) the 1985 Louis Harris Survey of Disabled Americans, conducted for the International Center for the Disabled in cooperation with the National Council on the Handicapped; and, 4) the 1988 National Rehabilitation Hospital Survey of Persons with Severe Physical Disabilities.

The project staff obtained data tapes for each of the above sources of data; created work files with key variables to be examined; computed frequency

distributions on all key variables; computed cross tabulations of outcomes by predictor variables; and performed factor analyses to identify data patterns that suggest groupings of variables to be further examined. In addition, the staff identified six representative SSDI scenarios (i.e., beneficiary types), and for each scenario programmed a “simulation model” using spreadsheet software to simulate the relationship between earned income and net total income (which includes earned income, program income, and in-kind benefits from various public programs).

**Results**—Interim results from the preliminary descriptive statistical analyses suggest that, in the working-age disabled population, productive work activity is positively correlated with educational attainment and general life satisfaction, and is negatively correlated with age at onset of disability and chronological age.

**Future Plans/Implications**—In the coming year, the project staff will perform step-wise regression analyses of outcome variables (such as employment status and desire to work) on key predictor variables (including various demographic factors and insurance coverage); construct reasonable causal models; and test models using linear structural relations programs, such as LISREL. The staff also will examine a variety of different private health insurance plans to determine the adequacy of coverage for persons with disabilities. Finally, the researchers will complete the spreadsheet simulation models programmed in year one, and will present results in the form of: 1) tables that depict earnings and program interactions for the six scenarios; and, 2) a two-dimensional representation of the theoretical framework that visually illustrates the interrelationships. Altogether, the results will provide insight on



how access to adequate employment-based health insurance affects a SSDI beneficiary's decision to seek employment.

#### Publications Resulting from This Research

None reported.

### [545] Rehabilitation Engineering Center

**William A. Hyman; Gerald E. Miller**

Texas A&M University, College Station, TX 77843

*Sponsor: Texas Department of Mental Health and Mental Retardation; National Science Foundation*

**Purpose**—This program provides rehabilitation engineering consultation at state Mental Health and Mental Retardation facilities, schools, and other sites. It brings bioengineering faculty and students in contact with facility personnel and provides for the execution of design projects which will benefit individual clients or be used within the facility for client treatment or education. The National Science Foundation funding supports the design work of the undergraduate students.

**Progress**—This is an ongoing program. Initial efforts consisted of meetings at each facility to acquaint the staff with the program and the types of projects consistent with available resources. This has been followed by frequent meetings to identify projects and implement designs. In addition, a design and electronics workshop was conducted to enhance the technical skills of on-site personnel.

**Results**—The direct result of this work is the delivery of new or modified adaptive equipment directly into the rehabilitation and special education settings. Seating problems have been addressed to provide greater stability to a variety of clients. Wheelchair accessories were developed, including custom trays and head-operated switches for interfacing with learning tools. Communication devices for non-verbal and motor-limited clients were developed which allow for simple selection from a limited menu. Similar systems for educating developmentally-delayed children were also provided, which accommodate both pictures and real objects. Additional projects included several types of interfaces between clients and environmental devices, and pre-vocational training devices which provide a reward feedback in the form of operation of a radio or similar appliance.

A variety of innovative physical therapy and occupational therapy equipment has been designed, including a vertical pole walkway as an alternative to parallel bars, hand and finger extension exercise aids, and a hand-squeeze exercise system. These devices provide a high degree of visual and auditory feedback to encourage the young user. Another project for young clients was the modification of a motorized jeep to substitute a joystick for foot controls. Stimulation devices to aid in eye tracking and a midline orientation were also designed for young clients. Sheltered workshop task design problems were addressed to improve workers' efficiency, and to bring new contracts to the workshop.

**Future Plans/Implications**—Experience with this program has demonstrated that there is a need for engineering design input for a variety of client problems at these facilities. This service model has advantages in that continuous engineering services could not be effectively utilized by these facilities at this time. Moreover, this program brings an array of expertise and experience to each facility as well as the resources of the University for fabricating projects. Future plans include expanding the program to cover more state and school facilities. Short course technology training for therapists and teachers will also be further developed. For the engineering student, this program provides an opportunity to solve real-world problems, obtain exposure to rehabilitation engineering, and gain a deeper understanding of individuals with handicaps and their needs.

#### Publications Resulting from This Research

**Rehabilitation Engineering Service Delivery Through Engineering Student Design Projects.** Hyman WA, Miller GE, in *Proceedings ICAART 88*, Montreal, 17, 1988.

**Engineering Student Design Projects in Physical, Occupational**



and Speech Therapy. Hyman WA, Miller GE, in *Proceedings of the 12th Annual RESNA Conference*, New Orleans, LA, 395-396, 1989.

Undergraduate Bioengineering Student Design Projects Applied to Real World Problems for the Handicapped. Miller GE, Hyman WA, *Int J Appl Eng Educ* 5(4), 1989.

## [546] Drug Effects on Bladder Smooth Muscle Contractility

**W.T. Woods, PhD; J.K. Bubien, PhD**

University of Alabama at Birmingham, Birmingham, AL 35294

**Sponsor:** National Institute on Disability and Rehabilitation Research

**Purpose**—Debilitating spasticity is an extremely serious secondary complication in patients with spinal cord dysfunction. Skeletal muscle relaxants are commonly prescribed to counteract spasticity, but experience has shown widely varying degrees of success. The bulk of previous research has addressed their effects on skeletal, and to a lesser extent, cardiac muscle. Their effects on smooth muscle have been considered only rarely.

This study examines the role of skeletal muscle relaxants on arterial and intestinal smooth muscle contractions in rats and on bladder smooth muscle in humans. Objectives of this study are to determine: 1) the effect of baclofen (Lioresal) and diazepam (Valium) on *in vitro* human bladder smooth muscle contractions induced by electrical pulses or acetylcholine; 2) the effect of baclofen and diazepam on *in vitro* rat and dog arterial and intestinal smooth muscle contractions induced by electrical pulses or acetylcholine; 3) whether diazepam or baclofen alter the responses of rat and dog bladder, arterial and intestinal smooth muscle induced to contract by bethanechol chloride; and, 4) whether diazepam or baclofen alter the length-tension relationship of rat and dog bladder, arterial and intestinal smooth muscle.

**Methodology**—Smooth muscle tissue specimens were obtained surgically in accordance with institutionally approved guidelines governing the involvement of human subjects in research projects. *In vitro* tension measurements resulting from artificial-

ly-induced contractions under control and experimental (with drug) conditions were obtained. Interspecies drug effects on different tissue specimens are being determined and compared.

**Preliminary Results**—Smooth muscle tissues from small intestine, blood vessels, and urinary bladder were obtained from 25 rats and 10 dogs. All experiments began with the establishment of a dose-response relationship between acetylcholine or bethanechol concentration, and resting and active tension. Shifts in the dose-response curves were assessed to shed light on mechanisms of action of the drugs under study.

Our overall conclusion is that drugs that block calcium ion influx may diminish urinary bladder tone. The clinical relevance of this observation is that the drugs used to reduce skeletal muscle spasticity may spare the bladder smooth muscle and allow normal or near normal bladder muscle tone to be maintained.

**Future Plans**—Differential effects of the drugs of interest will be tested in smooth muscle of different types and in different experimental animals. We will reinforce our efforts to obtain human smooth muscle samples for the study to facilitate our understanding of the clinical relevance.

### **Publications Resulting from This Research**

None reported.



# Section II

## Sponsor Index with Selected Program Summaries

### Part A. Department of Veterans Affairs

**Rehabilitation Research and Development Service**  
810 Vermont Avenue, N.W.  
Washington, D.C. 20420

*Margaret J. Giannini, M.D., Deputy Assistant Chief  
Medical Director for Prosthetics and Rehabilitation,  
Director, Rehabilitation Research and Development  
Service, Office of Clinical Affairs*

The mission of the Rehabilitation Research and Development Service program is to improve the quality of life of disabled veterans by making them more functionally independent. This mission is advanced through ongoing research projects in such priority areas as prosthetics/amputation, spinal cord injury, and sensory aids. Areas of special emphasis include aging, physical fitness, and psychosocial rehabilitation (e.g., dementia, schizophrenia, Alzheimer's disease, etc.).

During FY 1989, 189 rehabilitation R&D projects, including pilot projects, interagency studies, and special projects were conducted at 52 VA Medical Centers, including the two Rehabilitation Research and Development Centers at Hines, IL, and Palo Alto, CA, and the Atlanta Rehab R&D Unit in Decatur, GA.

In the areas of prosthetics, amputation, and orthotics, VA sponsored researchers are continuing to test new materials and using computer technology such as CAD/CAM to develop a new generation of artificial limbs. For spinal cord injuries, the use of robotics continues to be studied, as does the possibility that computer-controlled electrical stimulation can be used to restore function to paralyzed limbs. Research projects in the area of sensory aids include the continuing development of advanced mobility aids for visually-impaired people, digital hearing aids for those with hearing impairment, and various studies on treatment strategies and communication systems for aphasic individuals.

The VA Rehabilitation Research and Development Service sponsors a national program to review proposals submitted by researchers in the rehabilitation field. The Scientific Review and Evaluation Board for Rehabilitation Research and Development and Ad Hoc members assess proposals for their scientific and technical merit, budgetary needs, and time requirements. In 1989, the Board reviewed 100 proposals. There were 47 research projects approved in the five general priority areas: 1) prosthetics/amputation/orthotics; 2) communication,

sensory, and cognitive aids; 3) spinal cord injury; 4) aging; and, 5) schizophrenia-dementia. Included in this number were six pilot projects, approved to run for 1 year. Pilot projects are designed to test the feasibility of developing data, a technique, or a procedure prior to undertaking a regular research study.

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**VA Prosthetics Research and Development Center**  
103 South Gay Street  
Baltimore, MD 21202  
*Husher L. Harris, Manager*

Three units comprise the VA Prosthetics Research and Development Center: Office of Technology Transfer, Prosthetics Assessment and Information Center, and Rehabilitation Evaluation Unit.

**Office of Technology Transfer**  
*Husher L. Harris, Director (Acting)*

The Office of Technology Transfer (OTT) is responsible for the dissemination of information on completed and ongoing results of rehabilitation research and engineering developments. OTT publishes the *Journal of Rehabilitation Research and Development (JRRD)*, *Rehabilitation R&D Progress Reports*, and a clinical supplement series to *JRRD*.

The *Journal of Rehabilitation Research and Development* is a scientific/engineering quarterly publishing original research in rehabilitation. Supplements based on need and interest in the areas covered by *JRRD* and presented in a format appropriate for the clinician/practitioner are also published. The annual *Rehabilitation R&D Progress Reports* are summaries by investigators on the status of their current research. Portions of OTT publications are available electronically through the VA Rehabilitation Database on CompuServe.

OTT is also responsible for developing a broad scale VA Rehabilitation Database which, when completed, will provide up-to-date information on rehabilitation devices/services to VA facilities. Under current development are: 1) a comprehensive communication database on all speech and audiology devices (e.g., augmentative communication devices, assistive listening devices, hearing aids); 2) continual updates on devices; 3) feedback by



VA speech pathologists and audiologists who have used a specific device and who can be contacted for additional information; 4) evaluation and cost information; 5) interactive videos of clients using devices; 6) operation by a touch screen with "friendly" prompt menus in a standard directory format; and, 7) distribution by existing internal VA computer networks to VA clinics.

#### **Prosthetics Assessment and Information Center**

*Ronald I. Lipskin, Director*

The mission of the Prosthetics Assessment and Information Center (PAIC) is to evaluate and help deliver the benefits of rehabilitation technology to the VA on a national scale. Major goals are to maximize the safety and independence and to help improve the overall quality of life of disabled veterans.

PAIC's major activity is evaluation of commercially available rehabilitation products. During FY 1989, 43 evaluations were completed. Recommendations were submitted to the Prosthetic Technology Evaluation Committee (PTEC) in VA Central Office for eventual action by the VA Marketing Center. Most-evaluated products were wheelchairs. Others included van lifts, aids for the blind, walkers and canes, standing aids, and exercise equipment.

A new Clinical Interface Program (CIP) has delivered technical support (i.e., modified devices and technical guidance) to 29 veterans and VA clinicians in the Baltimore area. We are developing plans for a Technical Laboratory for Independent Living (TLIL) which will introduce practical technology into the daily routine of disabled veterans and VA health care deliverers. We are also implementing action for novel structural analysis techniques to support the VA wheelchair standards program, which will have a major impact on the International Standards Organization (ISO).

#### **Rehabilitation Evaluation Unit**

*Sal Sheredos, Director (Acting)*

The primary goal of the VA Rehabilitation Evaluation Unit (REU) is to provide disabled veterans the opportunity to receive the benefits of modern technology and, at the same time, protect them from inferior and/or unsafe products. An additional goal is the enhancement of the health care delivery system through the introduction of state-of-the-art technologies.

REU undertakes evaluation projects that are generated through the VA health delivery system, which is comprised of 172 medical centers throughout the nation. During FY 1989, REU's activities included the application of computer technology for hearing impairment and increased mobility through the utilization of ultrasonic sensing detectors. This fostered the development of assistive devices to improve the quality of life of people with hearing impairment and new orthotics/prosthetics for individuals with amputations.

Of special interest to the health care delivery system will be the utilization of a computer-driven hearing aid

fitting system and the ultrasonic sensing process. These systems will enable the fabrication of customized footwear that will improve therapeutic and technical precision and lead to reduced costs, when compared to conventional custom shoe fabricating techniques. REU worked in cooperation with its industrial partners such as 3M, L&M Electronics, Inc., Bradley Corp., and Eureka Laboratories to develop and manufacture the pre-commercial prototypes used in the clinical evaluation trials.

The following are reports at the two R&D Centers and the R&D Unit.

#### **Rehabilitation Research and Development Center**

**Edward Hines Jr., VA Hospital**

**Hines, IL 60141**

*John Trimble, Ph.D., Director*

During fiscal year 1989, the Hines Rehabilitation Research and Development Center developed new initiatives that increased the scope of our research programs, fostered greater interaction with our academic colleagues, and improved our ability to disseminate the results of our research and development programs. Our research program has been revised to simplify and encourage interdisciplinary studies and clinical collaboration. Our new research branches, cognitive and perceptual sciences, kinesiology, and rehabilitative neuroscience, build on our strengths in orthopedic biomechanics and neuroscience. We have focused our research on a central theme: restoring, ameliorating, and supplementing mobility. This provides for the growth and unification of our activities while giving us the greatest opportunity to impact positively on the quality of life of disabled and infirm veterans.

We have created a "satellite program" with the University of Illinois at Urbana-Champaign (UIUC) that promises unique opportunities for disability-related research. The nucleus of the program is UIUC's Division of Rehabilitation Education Services, a unit of the College of Applied Life Studies that provides medical, personal, and educational support to university students with disabilities. The division's 40-year history of providing service and opportunities to students with disabilities makes it a logical and unique focus for the satellite program. Our partners in the satellite program include faculty from the departments of kinesiology, electrical engineering, mechanical engineering, general engineering, industrial engineering, and psychology. Our presence on the University campus also provides us with access to unique resources such as the Beckman Institute for Advanced Studies and the National Center for Supercomputing Applications. The UIUC/Hines satellite program gives us the opportunity to focus the talents of the faculty and unique resources of one of the best-ranked universities in the United States on the problems of disabled veterans. Our new technology transfer program represents a new spirit of cooperation between the



Center, people with disabilities, and industry. The core of this program is the Center's Rehabilitation Technology Consortium (RTC), a partnership of local businesses, organizations that represent people with disabilities, economic development cooperatives, and universities. The RTC encourages the exchange of ideas between its members and more rapid transfer of new discoveries and technologies. Through the RTC, we have brought new product ideas to the attention of University faculty and business, provided market and demographic information to industry, and nurtured entrepreneurial ventures in the private sector. The RTC concept underscores our commitment that a partnership between people with disabilities, researchers, and industry is essential for providing disabled veterans with the techniques and devices they need to lead productive lives.

Our initiatives of the 1980's have laid the foundation for the coming decade. We anticipate that the partnerships we have formed and the prevailing spirit of cooperation will create exciting new ventures that will lead to concepts, devices, and techniques to satisfy the needs of America's disabled veterans.

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**Rehabilitation Research and Development Center**  
**VA Medical Center**  
**Palo Alto, CA 94304-1200**  
*Felix E. Zajac, Ph.D., Acting Director*

The Palo Alto Rehabilitation R&D Center continues to work toward bringing the finest engineering and medical science technology to veterans with physical or cognitive disability. It is the intent of our labor that new knowledge

about disability, new methods of treatment, and new assistive devices will help lead to independent and productive lives where this would not otherwise be possible.

Achievement of this objective is facilitated by affiliation with the Stanford University Schools of Engineering and Medicine. These and other collaborative associations are especially important to our mission. Collaborating institutions include: NSAS Ames Research Center, Massachusetts Institute of Technology, University of Maryland, Santa Clara University, Delft University (Netherlands), Children's Hospital at Stanford, Santa Clara Valley Medical Center, American Foundation for the Blind, Smith-Kettlewell Eye Research Foundation, and the Paralyzed Veterans of America.

The Orthopaedic Biomechanics Program continues to develop computational models and experimental paradigms to form a unified model for the relationship between mechanical strain energy and the growth, development, and eventual resorption of bone and cartilage. The validation of a unified theory has important implications for the design of joint replacement orthoses and for fracture healing. The Neuromuscular Systems Program continues to develop computational models of nerve, muscle, and skeletal mechanics. In combination with electrophysiological and kinesiological experiments, these studies constitute a unique interdisciplinary synthesis. They support optimal control strategies for restoration under dynamic interactions among neuromusculoskeletal components and mobility in paraplegics and the elderly through surgery simulations. The group is now integrating artificial intelligence technology in mobility, manipulation, navigation, communication aids, and cognitive orthoses. Clinical studies in each of these areas engage a large portion of our effort. In particular, a third generation Desktop Vocational Assistant Robot has been placed in an off-station vocational field study and is awaiting approval for limited production.

Several devices and methodologies developed and/or reported in previous years have survived the arduous path from concept to production reality. New federal laws and renewed emphasis on a structured approach to technology transfer have helped to make this a particularly productive year.

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**Decatur, GA 30033**

*Franklyn K. Coombs, Director*

The Unit is composed of four branches: Prosthetics, Biomaterials/Biomechanics, Neurophysiology, and Sensory and Behavioral Sciences. The Prosthetics branch conducts studies relating to artificial limbs, gait analysis, postural sway, wheelchairs, wheelchair cushions, and soft tissue mechanics. The Biomaterials/Biomechanics branch conducts studies relating to electrical stimulation for osteogenesis, artificial joints, and hard-tissue mechanics. The Neurophysiology branch studies vestibular functions, falls and auditory aspects of balance, EEG analysis and sleep disorders, motor control systems, and incontinence. The Sensory and Behavioral Sciences branch studies visual and/or hearing impairment, spatial cognition, disorientation, wandering, wayfinding, and mobility.

The Unit conducted 10 merit approved research projects during FY 1989.

The Center conducted 12 Core-supported pilot studies in 1989. The purpose of the pilot studies was to obtain preliminary data to facilitate development of high quality merit review applications. The following are titles of pilot studies conducted this year:

1. Design of a Radiotranslucent Chair for X-ray Analysis of Dysphagia
2. Design of Toilet Fixtures for the Disabled (Transfer and Access)
3. Evaluating Methods for Dissemination of Low Vision Information
4. Assessment of Independent Living Skills for Elderly People with Impaired Vision
5. Development of Extended Norms for the Wechsler Adult Intelligence Scale—Revised (WAIS-R)
6. Dynamic Posturography in Elderly People
7. Balance Training in Stroke Rehabilitation
8. Development of Computer Simulation of Wandering Behavior of Elderly Nursing Home Patients
9. Fatigue Measurements of Shock Absorbing Floor Covering

10. Magnetic Stimulation of Focal Brain Sites
11. Development of Norms for Elderly People for a Physical Exercise Intervention
12. Evaluation of Video Data of Falls

### **Laboratory Resource Developments**

**Vision.** The vision laboratory provides support for a variety of basic and applied research in visual perception and visual function. Equipment on hand includes devices for measuring dynamic and static visual acuity, visual fields, and sensitivity to contrast. Equipment to support the study of oculomotor function and distance and depth perception is also available. Several innovative measures of accommodative response, distance and depth judgments, and contrast sensitivity are currently being used to compare visual function and performance between younger and older observers who have no organic pathology. The emphasis of this research is to relate traditional clinical measures of visual function with the more behaviorally-based measures and to test the observers' responses to visual environments from real world situations. In future phases of the research, subjects manifesting typical age-related visual pathologies such as macular degeneration, glaucoma, and cataracts will be compared with the normative population under current study.

**Audition.** Laboratory resources support a variety of basic and applied research in audition and psychoacoustics. They include test apparatus for pure tone sensitivity, free-field sound localization, and detection of sound shadow. Studies are also being conducted to determine echolocation and spectral shape.

**Video Analysis.** The video analysis laboratory permits behavioral researchers to obtain detailed and accurate observational data through the use of video tape. Relevant data are edited onto composite tapes and these tapes are scored a sufficient number of times by multiple viewers to obtain statistical reliability. The system, consisting of a multiple-camera surveillance package with time-lapse recorders, detection devices, audio, and infrared viewing capabilities, is particularly useful in studying infrequent events such as falls or wandering patterns of elderly individuals in nursing homes.

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17 Court St., Boston, MA 02108

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44 Cummington St., 5th floor, Boston, MA 02215  
*Carlo DeLuca, Director*

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**Action Research for the Crippled Child**  
Vincent House, North Parade, Horsham, West Sussex RH12 2DA, UK  
*A.N. Brearley-Smith, OBE, Director*

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75-20 Astoria Blvd., Jackson Heights, NY 11370-1178  
*James Peters, Director*

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75-20 Astoria Blvd., Jackson Heights, NY 11370-1178  
*James Peters, Director*

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1383 Piccard Drive, Rockville, MD 20850

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**American Paralysis Association**  
500 Morris Ave., Suite 309, Springfield, NJ 07081  
*Margaret Brown, PhD, Director of Research*

The American Paralysis Association is a nonprofit organization that funds research in the area of spinal cord injury, with emphases on neural regeneration, prevention of secondary neuronal damage, and cures for chronic paralysis (especially paralysis consequent to spinal cord injury).

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1111 18th St. NW, Suite 501, Washington, DC 20036

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Otto Broe A/S, Formervangen 9, Glostrup DK-2600, Denmark  
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2165 Bunker Hill Drive, San Mateo, CA 94402

*John de Miranda, Director*

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1600 Clifton Road, NE, Atlanta, GA 30333

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Houston, TX

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Central Development Unit, Prostheses-Orthoses, Repatriation

General Hospital, Banksia St., Heidelberg 3081, Australia

*Marius Fahrner, Director*

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Grants and Contracts Office, P.O. Box 3001, Durham, NC  
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24 Ferrand Drive, Don Mills, M3C 3N2 Ontario, Canada

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**Eastern Paralyzed Veterans Association**

432 Park Ave. South, New York, NY 10016

*James J. Peters, Executive Director*

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Department of Health and Human Services, Executive Plaza  
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Department of Health and Human Services, 900 Rockville  
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**National Institute on Disability and Rehabilitation Research**

Department of Education, 400 Maryland Ave. SW,  
Washington, DC 20202

*James B. Reswick, ScD, Acting Director*

Established by the 1978 amendments to the Rehabilitation Act, the National Institute on Disability and Rehabilitation Research (NIDRR) is responsible for managing a comprehensive program of disability-related research and training for professionals who provide services and conduct research. NIDRR's mandate encompasses all major areas of applied research. In addition to the project listed below, NIDRR co-sponsors research with other organizations reporting in this publication, which is noted in this index and in the text of the progress reports.

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Department of Health and Human Services, 900 Rockville  
Pike, Bethesda, MD 20892

*Dr. James Wyngaarden, Director*

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**National Science Foundation**

1800 G Street NW, Washington, DC 20550

*Erich Bloch, Director*

The Bioengineering and Aiding the Disabled Program of the National Science Foundation provides funding for biomedical engineering research directed toward the characterization, restoration, or substitution of normal physiological function. The emphasis is on fundamental research that will support the emergence of new technology.

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**Natural Sciences and Engineering Research Council of Canada**

200 Kent St., Ottawa, Ontario K1A 1H5, Canada

*Dr. Arthur May, Director*

The Natural Sciences and Engineering Research Council is Canada's largest research granting agency. While it does not target its research directly in the area of rehabilitation, the Council does fund research in the engineering of prosthetic devices and artificial limbs, as well as computing, communications, and instrumentation technology.

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**Netherlands Organization for Research**

Faculty of Human Movement Sciences, The Free University, 1081 BT Amsterdam, The Netherlands

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**NeuroMuscular Research Center**

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Brussels, Belgium

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**Office of Special Education Programs**

Department of Education, 400 Maryland Ave. SW, Switzer Bldg. Rm. 4614-M/S 2313, Washington, DC 20202

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Toronto, Ontario, Canada

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**Ontario Ministry of Education**  
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**Ontario Ministry of Health**  
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**Orthokinetics Research Foundation**  
5 Sedgemoor Court, Williamsville, NY 14221  
*Mo Neeman, PhD, Director*

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**Orthopaedic Research and Education Foundation**  
444 N. Michigan Ave., Chicago, IL 60611

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**Paralyzed Veterans of America, Spinal Cord Research Foundation**  
801 18th Street, NW, Washington, DC 20006  
*R. Jack Powell, Executive Director*

The Spinal Cord Research Foundation (SCRF) was originally founded by the Paralyzed Veterans of America in 1975. SCRF sponsors research projects and fellowships in the basic sciences (neuroanatomy, neurophysiology, urinary, cardiopulmonary) that are designed to increase scientific knowledge of spinal cord

injury and dysfunction. SCRF also funds research in clinical, technological, and psychosocial areas of importance to persons with spinal cord injury or dysfunction.

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## **JRRD On-Line**

Selected portions of the *Journal of Rehabilitation Research and Development* (JRRD) are being put on-line as part of the **VA Rehabilitation Database**, and coverage will be expanded monthly. At present, abstracts of all scientific articles, Calendar of Events, and current Publications of Interest are available to readers through **JRRD On-Line**. *Rehabilitation R&D Progress Reports* for 1989 and a listing of commercially available adult wheelchairs are also on-line.

Subscribers to CompuServe may access **JRRD On-Line** by typing "GO REHAB" (or "GO HUD" and selecting the "Research and Development" menu option).

**JRRD On-Line** is a part of the **VA Rehabilitation Database**, which is being developed to provide consumer rehabilitation research news bulletins and clinical information, as well as the *Journal*, *Progress Reports*, and other publications. A description of the **VA Rehabilitation Database** is presented on p. 511.

### **USING THE EXISTING VA REHABILITATION DATABASE ON COMPUERVE**

#### **I. What you need: Access to equipment and software.**

- Personal computer
- Modem with communication software
- Subscription to CompuServe (connect time costs range from \$6/hour [300 baud] to \$12.50/hour [1200 baud], prices vary with baud rate).

#### **II. You can get help if needed:**

- VA Rehabilitation Database - write or call  
Dori Grasso  
Office of Technology Transfer (110A1)  
VA Prosthetics R&D Center  
103 South Gay Street  
Baltimore, Maryland 21202  
Phone: 301-962-1800

#### **III. The VA Rehabilitation Database is user friendly:**

- A user friendly system is a central design feature of the database. No previous experience with computers is necessary and very little learning is required. The system makes obtaining information about rehabilitation devices as easy as making a telephone call.

#### **IV. Eligibility:**

- The VA Rehabilitation Database is available for use by anyone who subscribes to CompuServe.

#### **V. Free/discount services:**

- The Office of Technology Transfer (OTT) can assist new users in obtaining limited free CompuServe time as an introductory service.



# VA REHABILITATION DATABASE: THE DREAM

## SCIENTIFIC

*Journal of Rehabilitation Research and Development On-Line*

### Purpose

*To provide greater accessibility to the Journal's scientific contents for use by rehabilitation researchers and other interested readers.*

### Objectives

#### Short-term:

- 1) "Publication" of the abstracts of individual articles immediately upon acceptance, well in advance of printed *Journal* publication.
- 2) Ready reference any time of day or week.
- 3) Expanded circulation of scientific research information.
- 4) Make *Journal* contents available to blind readers through use of speech synthesizers.

#### Mid-term:

- 1) Title/Author/Subject Index of all JRRD articles published, to be updated yearly.

- 2) Allow readers to select material pertinent to their individual need.

- 3) Provide interactive forums for exchange on scientific issues.

#### Long-term:

- 1) Full text searching of rehabilitation literature.
- 2) One-stop access to rehabilitation literature.

#### Current contents:

- 1) **JRRD On-Line.** Abstracts of all articles published or accepted for publication to date.
- 2) *Rehabilitation R&D Progress Reports.*
- 3) Current Publications of Interest.
- 4) Calendar of Events.
- 5) Wheelchairs: Commercially available adult wheelchairs.
- 6) Members, Technology Transfer Committee [A special interest group, part of RESNA (Association for the Advancement of Rehabilitation Technology)].

## CLINICAL

### Purpose

*To provide clinical personnel (e.g., physicians, physical therapists, audiologists, etc.) with current, accurate, and comprehensive information on rehabilitative devices.*

#### First on-line:

- 1) Assistive hearing devices.
- 2) Automotive adaptive equipment.

#### Planned enhancements:

All rehabilitative devices available or under development in the United States.

## CONSUMER

### Purpose

*To promote the transfer of technology to potential users who can benefit from information on research results in many ways, including direct purchase of appropriate equipment, enrichment of ability to work with rehabilitation professionals, personal adjustment, and participation in service organization activities.*

#### Desired contents:

Selected periodic reports on VA sponsored rehabilitation R&D research.

Selected biweekly news bulletins focusing on scientific developments of interest to consumers.

HV1786 Todd, Seldon P (ed.).  
R266 Rehabilitation R&D  
1989 Progress Reports 1989:  
26th Annual supplement of  
the Journal of Research

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February 1990